NASA TECHNICAL
TRANSLATION

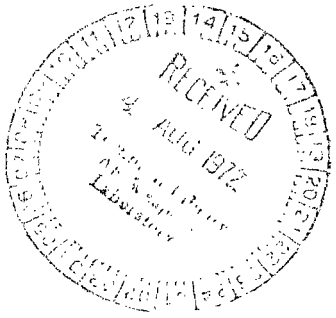
NASA TT F-717
c. 1

LOAN COPY: RETI
AFWL (DOU
KIRTLAND AFB,

NASA TT F-717

PHYSICAL CHARACTERISTICS OF THE GIANT PLANETS

Edited by V. G. Teyfel'



"Nauka" Press of the Kazakh SSR
Alma Ata, 1971

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1972

TECH LIBRARY KAFB, NM
0069053

PHYSICAL CHARACTERISTICS OF THE GIANT PLANETS

Edited by V. G. Teyfel'

Translation of "Fizicheskiye kharakteristiki planet-gigantov." "Nauka" Press of the Kazakh SSR, Alma Ata, 1971

For sale by the National Technical Information Service, Springfield, Virginia 22151
$3.00

ANNOTATION

This handbook contains almost all the information which presently exists about the physical properties of the atmospheres and the internal structure of the giant planets (Jupiter, Saturn, Uranus, and Neptune). This information is based mainly on the data of astrophysical observations and in part on theoretical calculations. All the data are presented in the form of tables and graphs, accompanied only by short explanations. An extensive guide to the literature on the giant planets is also presented, including mainly papers published during the last 20 years.

This handbook may be useful to astronomers, both professionals and amateurs, students, lecturers, and all those individuals who are interested in the contemporary state of planetary research.

TABLE OF CONTENTS

	PAGE
Introduction	ix
JUPITER	
Dimensions	1
Mass and Gravitational Acceleration	2
Rotation	2
Apparent Stellar Magnitude	5
Color Index	5
Geometric Albedo	6
Spherical Albedo, Phase Integral, and Phase Function	7
Spectral Reflectivity	9
Ultraviolet Absorption	12
Molecular Absorption Bands in the Spectrum	13
Distribution of the Intensity of Molecular Absorption Across the Planet's Disk	19
A General Scheme of the Atmosphere's Structure	25
Chemical Composition of the Outer Atmosphere	27
Other Possible Components of the Atmosphere	31
Models of the Atmosphere's Chemical Composition	35
Radiation Temperature	37
Radiometric Temperature	39
Rotational Temperature	42
Brightness Temperature in the Radio Region	43
Observational Estimates of the Atmospheric Pressure	45
Optical Thickness of the Outer Atmosphere	45
Models of the Outer Atmosphere's Structure	46a
Optical Properties of Cloud Details	57

PAGE

Polarization Properties 60
Brightness Distribution Across the Disk 61
Scattering Indicatrix of the Cloud Layer 63
Single-Scattering Albedo of Particles of the Cloud Layer 64
The Structure and Composition of the Cloud Layers 65
The Red Spot 72
Models of the Lower Atmosphere's Structure 79
The Total Thickness of the Atmosphere 81
Internal Thermal Energy 82
Circulation and Active Processes in the Atmosphere 83
Structure of the Upper Atmosphere 92
Photochemical Processes in the Upper Atmosphere 94
Searches for Emission in the Upper Atmosphere 95
Rotational Period of the Sources of Radio Emission 96
Decimetric Radio Emission 97
Decametric Radio Emission 100
Effect of the Satellites on the Radio Emission 103
The Magnetic Field and the Magnetosphere 104
The Ionosphere 105
The Radiation Belts 106
Correlation with Solar Activity and With Visible Details of Jupiter 107
Radar Observations of Jupiter 107
Internal Structure 108

SATURN

Dimensions 114
Mass and Gravitational Acceleration 114
Rotation 115
Optical Characteristics 115

PAGE

Color Characteristics 116
Spectral Reflectivity 117
Brightness Distribution Across the Disk 118
Molecular Absorption Bands in the Spectrum 120
Radiative Temperature 123
Radiometric Temperature 123
Rotational Temperature 124
Chemical Composition of the Outer Atmosphere 125
Models of the Structure of the Outer Atmosphere 126
Temperature of the Exosphere 128
Saturn's Rings 129
Radio Emission 135
Internal Structure 136

URANUS

Dimensions 141
Mass and Gravitational Acceleration 141
Integral Optical Characteristics 142
Molecular Absorption Bands in the Spectrum 143
Chemical Composition of the Outer Atmosphere 145
Radiative Temperature 146
Radiometric Temperature 147
Rotational Temperature 147
Model of the Outer Atmosphere's Structure 147
Radio Emission 149
Internal Structure 149

NEPTUNE

Dimensions 152
Mass and Gravitational Acceleration 152
Integral Optical Characteristics 153
Molecular Absorption Bands in the Spectrum 154

PAGE

Chemical Composition of the Outer Atmosphere 155

Radiative Temperature 155

Upper Atmosphere 156

Model of the Outer Atmosphere's Structure 156

Radio Emission 157

Internal Structure 158

REFERENCES

I. Reviews and Monographs 160

II. Morphological, Photometric, and Polarization Investigations 163

III. Spectral and Radiometric Investigations 173

IV. Theoretical Investigations and Laboratory Experiments 186

V. Radioastronomical Investigations 198

INTRODUCTION

The purpose of this book is to give the reader the necessary handbook information, in as compact a form as possible, about the physical characteristics of each of the four representatives of the giant planets: Jupiter, Saturn, Uranus, and Neptune. These planets form a very specific group of celestial objects; they are sharply distinguished by their properties from all the other members of the solar system. The information which presently exists on the giant planets is still based exclusively on ground-based investigations, if one does not consider several experiments carried out with the help of balloon telescopes and high-altitude rockets. /3*

Several monographs have recently appeared which are partially or completely devoted to the problems of the study of the giant planets. These include Fizika planet (Physics of the Planets) by V. I. Moroz (Moscow, "Nauka" Press, 1967), Atmosfera planety Yupiter (Atmosphere of the Planet Jupiter) by V. G. Teyfel' (Moscow, "Nauka" Press, 1969), the "Hnadbook of the Physical Properties of the Planet Jupiter" published by NASA under the editorial direction of C. Michaux in 1967 (the Russian translation of this handbook appeared in 1970 from the "Mir" Press), and also A. F. Alexander's monographs "The Planet Saturn" (London, 1962) and "The Planet Uranus" (London, 1965).

The main emphasis in the present handbook-compilation is devoted to quantitative data presented mainly in the form of tables and graphs with just the most essential explanations.

The information presented essentially generalizes the results published in the original articles of Soviet and foreign authors. Only in isolated cases did we turn to reviews and monographs or did we carry out additional calculations and the plotting of graphs.

---

*Numbers in the margin indicate pagination in the original foreign text.

The bibliographical section contains a list of almost all the papers on the giant planets published prior to 1970, with the exception of articles of a purely amateur nature based on the results of visual observations. /4 Citations in the text to papers used are given in square brackets along with the names of the investigators. The year of the observations is indicated in parentheses in isolated cases, in addition to the year of publication. The bibliography is set up along subject divisions.

The giant planets are distinguished from the planets of the terrestrial group by their large distances from the Sun, their significantly larger dimensions, and their low average density, which is caused by the fact that they consist mainly of light elements, primarily, hydrogen and helium. In this respect the giant planets are more similar to the Sun than to the other planets of the solar system, a fact which should be associated in a specific way with the distinctive features of their formation and evolution at great distances from the Sun.

Regardless of the fact that the giant planets obtain tens and hundreds of times less energy from the Sun than does the Earth, active processes, which appear both in the optical region and in radio radiation, are observed in their atmospheres (particularly Jupiter's). The possibility that internal sources of thermal and electromagnetic energy may play an important role is not excluded.

Data on the physical conditions even in the outer layers of the giant planets atmospheres are still extremely meager, without even talking about the deep layers of the atmospheres, and the interiors of such planets are still inaccessible to direct observations. Therefore, our ideas of the internal structure of the largest objects of the solar system are based only on theoretical calculations.

Many phenomena which were observed long ago in the giant planets, in particular, non-thermal radio emission, instability of the atmospheres, and

the puzzling phenomenon of the Red Spot on Jupiter, have not yet received a conclusive explanation. The large distance of these planets severely limits the possibility of ground-based investigations due to disturbances on the part of the terrestrial atmosphere, insufficient resolving power of the instruments, and the comparatively low sensitivity of the radiation receivers. There are no doubts that the application of the means of space technology significantly broadens the outlook for the study of the giant planets, although regular observations will be accessible for a long time yet only to ground-based observatories.

Notwithstanding the significant progress in the study of the giant planets in recent years, it is fully understood that the existing observational information can still not claim complete certainty, and in some cases is even simply contradictory. It is not always possible to give preference to certain results, particularly if one bears in mind the fact that the /5
atmospheres of these planets are unstable and that many characteristics (both optical and radioastronomical) are subject to significant variations in time. One usually employs a more or less simplified theory, and correspondingly approximate calculations, in the interpretation of the observational data. Of course, the parameters obtained in this way depend not only on the accuracy of the observations but also on the method of their interpretation. The name "Handbook-Compilation" itself emphasizes this volume's difference from the usual handbooks, which contain the characteristics which have been established firmly enough. Many of the values presented here either require further checking and refinement or are in general extremely approximate or tentative. Nevertheless, one can conceive that the "Handbook-Compilation" is useful for those individuals who are occupied with investigations of the planets or are in need of obtaining information about the contemporary state of their study. It is natural that the first attempt to compile a handbook of such a nature can be not quite successful; it is possible that some papers were left out and were not given in the text or in the bibliography. One would hope that there are not very many papers in this category. The authors take this opportunity to express their gratitude to Prof. D. Ya. Martynov

(Shternberg State Astronomical Institute) for advice and a number of valuable remarks during the preparation of this handbook for the press.

DIMENSIONS

Data on the dimensions refer to the visible profile of Jupiter, i.e., to the surface of the cloud layers. The dimensions and the shape of the "solid" planet are still not known, and can be estimated only tentatively in the case of a specified depth for the atmosphere, which is also not known.

Angular dimensions at a distance of 1 A. U.:

Average diameter, D''	192",25±0",29
Equatorial diameter, D''_{eq}	196",53±0",29
Polar diameter, D''_{p}	183",68±0",29

Linear dimensions

Average diameter, $\bar{D}$	139370 ± 200 km = 10.94 ± 0.02 D_E
Average radius, $\bar{R}$	69685 km
Equatorial diameter, D_{eq}	142470 ± 200 km
Equatorial radius, R_{eq}	71235 km
Polar diameter, D_p	133160 ± 200 km
Polar radius, R_p	66580 km
Optical oblateness, ε_{opt}	0.0654 (1:15.3)
Eccentricity of the ellipsoid	0.23146
Volume ($V_E = 1$)	1308
Dynamical oblateness (Brouwer and Clemence [1-2], ε_{dyn}	0.06518 (1:15.34)

MASS AND GRAVITATIONAL ACCELERATION

Mass

M_J	1.899×10^{30} g
$M_{\odot}=1$	317.38 ± 0.02
$\frac{M_{\odot}}{M_J}$	1047.60 ± 0.05 1047.381 ± 0.020 (1) 1047.387 ± 0.004 (2)
mean density, $\bar{\rho}$	1.327 ± 0.008 g/cm^3

/7

ACCELERATION OF THE FORCE OF GRAVITY AT JUPITER'S VISIBLE SURFACE

(R_{eq} = 71387 km, ε = 0.06518, $P_{rot} = 9^h52^m$)

Latitude, ϕ	g, cm/sec^2	g/g_E
0°	2312	2.36
15	2358	2.40
30	2404	2.45
45	2496	2.55
60	2589	2.64
75	2656	2.71
90	2681	2.74

The escape velocity at the surface is equal to 60.9 km/sec.

ROTATION

The zonal nature of the rotation of Jupiter's visible surface permits dividing the planet into three zones according to their average rotational velocities. These zones are the equatorial (System I) and the temperate zones (Southern and Northern, System II). Based on the periodicity of bursts of decametric radio emission, system III has been derived for the radio /8 sources. However, the rotational velocities of individual features in Jupiter's cloud layer can deviate significantly from the average values for details of a system of rotation at the corresponding latitude. The scatter of such values is shown graphically (Figures 1-6).

---

(1) Value derived in 1967 by W. Klepczynski from an analysis of the motion of the asteroid 32 Europa [IV—73].

(2) Value derived by O'Hadley (1968) from an analysis of the motion of an asteroid 65 Cybele [IV—92].

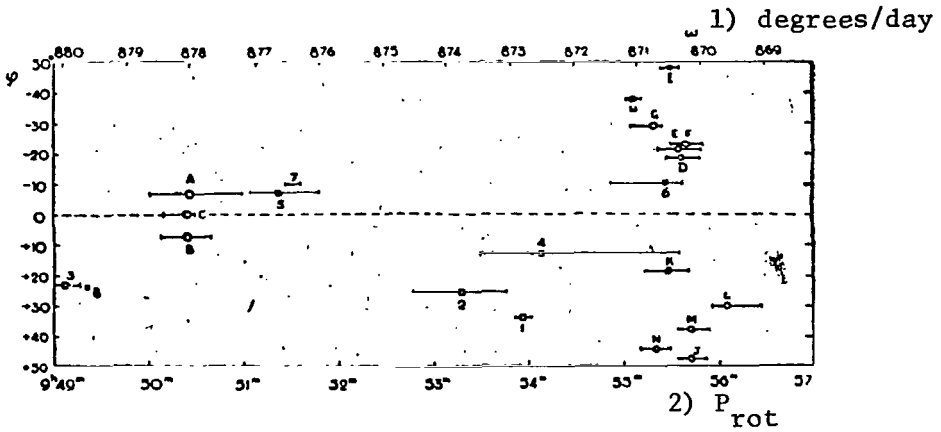


Figure 1. Periods and angular rotation rates of various zonal currents on Jupiter (according to Peek's summary). A) N. edge of the S. equatorial belt and S. part of the equatorial zone; B) S. edge of the N. equatorial belt and the N. part of the equatorial zone; C) Middle of the equatorial zone; D) N. component of the S. equatorial belt; E) S. tropical zone; F) Red Spot; G) S. temperate belt and zone; H) S. S. temperate belts and zone; I) S. S. S. temperate belt and S. polar region; J) N. polar region; K) N. tropical zone and N. edge of the N. equatorial belt; L) N. temperate belt (A current); M) N. N. temperate belt; N) N. N. N. temperate belt; 1) dark spots and cusps on the S. edge of the N. N. temperate belt; 2) N. temperate belt (B current); 3) N. temperate belt (C current); 4) spots in middle of the N. equatorial belt; 5) equatorial zone (B current); 6) spots in the middle of the S. equatorial belt; 7) bright spots in the S. equatorial belt (1900-1903); 8) dark spot (1964).

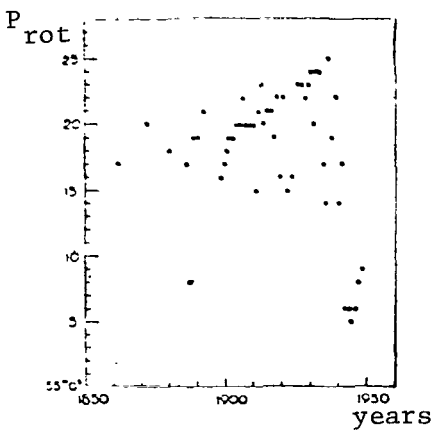


Figure 2. Rotational periods of details of the S. temperate belt and zone (S. temperate current) according to Runcorn.

The formula for conversion from longitudes in system II to radio longitudes in system III is: $L_{III} = L_{II} + 0{,}2742\ (JD - 2433339{,}5)$ where JD is the Julian date at the instant of observation.

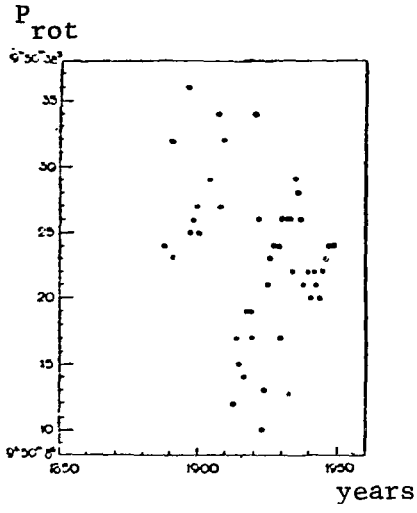


Figure 3. Rotational periods of details in the N. branch of the large equatorial current (on the S. edge of the N. equatorial belt and the N. part of the equatorial zone) according to Runcorn.

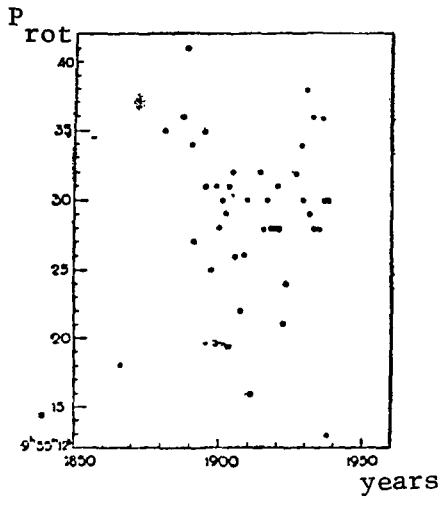


Figure 4. Rotational periods of details in the N. tropical zone and the N. part of the N. equatorial belt (the N. tropical current) according to Runcorn.

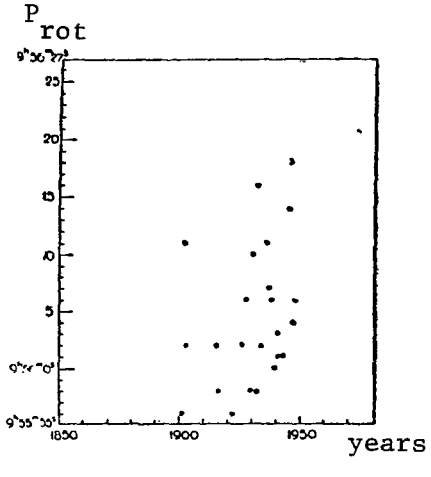


Figure 5. Rotational periods of details in the N. temperate A current (according to Runcorn).

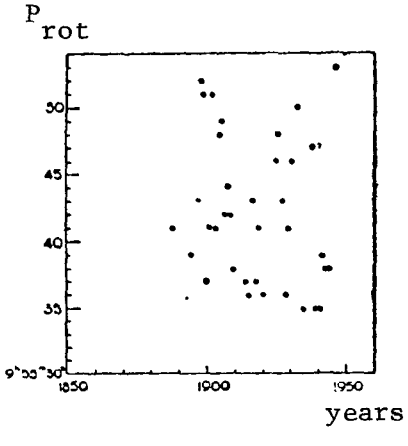


Figure 6. Rotational periods of details in the N. temperate belt and zone (according to Runcorn).

SYSTEMS OF ROTATION AND LONGITUDE RECKONING ON JUPITER

/9

System	Period of rotation, P	Angular velocity		Linear rotational velocity at the visible surface, km/sec
		degrees/day	radian/sec	
I $\lvert\varphi\rvert < 12°$ (optical)	$9^h50^m30^s.003$	877.90	$1.77 \cdot 10^{-4}$	12.64 ($\varphi = 0°$)
II $\lvert\varphi\rvert > 12°$ (optical)	9 55 40.632	870.27	$1.76 \cdot 10^{-4}$	12.26 ($\varphi = 12°$)
III (radio)	9 55 29.37	870.544		

APPARENT STELLAR MAGNITUDE

Jupiter's brightness varies noticeably with time, which is associated both with the variation in its distance from the Earth and with the variation in the planet's total reflecting power due to the variable nature of the width and intensity of the dark cloud belts on its disk (Figure 7). The average values of its brightness are as follows:

/10

Characteristic	Value
Apparent stellar magnitude for an average opposition	$\overline{m_V} = -2.^m55$
Average stellar magnitude referred to a distance of 1 A.U. for a phase angle of 0°	$\overline{V}(1.0) = -9.^m24$ [I—6]
Amplitude of the temporal oscillations V (1.0)	$0.^m48$ (Harris1965 [I—6])
Possible periodicity of the brightness oscillations	11.6±0.4 years (Becker, 1933 [I—6])
	11.04 years (Rubashev, 1964 [I—10a])

COLOR INDEX.

The normal color index is $C = m_{ph} - m_v$ where m_{ph} is the photographic stellar magnitude (λ_{eff} = 4400 Å) and m_v is the visual stellar magnitude (λ_{eff} = 5500 Å). Jupiter's color undergoes, just as its brightness does, some variations due to the variability in the brightness and color of individual belts and zones on its disk:

Characteristic	Value
Average normal color index	+ 0, $^{m}86$
Limit of the variations	$\pm$ 0, $^{m}2$
Possible periodicity of the variations	11 - 12 years (Sharonov, 1958 [1 - 12])

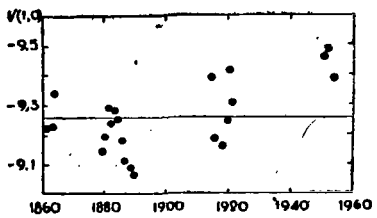


Figure 7. Variation in Jupiter's integral brightness (according to Harris).

Special color indices calculated from the differences of the planet's stellar magnitudes in the (U, B, V, R, I) system according to Harris [1-6]:

Region of the spectrum	U - B	B - V	V - R	R - I
Color index	+0, $^{m}48$	+0, $^{m}83$	-0, $^{m}50$	-0, $^{m}04$

GEOMETRIC ALBEDO

The geometric albedo is the ratio of the brightness of the planet's disk at a phase angle of 0° to the brightness of an absolutely white flat screen with a diameter equal to the planet's diameter and positioned perpendicularly to the sunlight at the same distance from the Sun as the planet is.

The geometric albedo in the infrared region according to R. Danielson (1965 [III—54]) and V. I. Moroz (1961 [III—15]) is presented graphically (Figures 8 and 9).

VALUES OF JUPITER'S GEOMETRIC ALBEDO /11

Characteristic	Value	Author, Year
Geometric albedo in the U, B, V, R, I, system	$p(U)=0.270$ $p(B)=0.370$ $p(V)=0.445$ $p(R)=0.466$ $p(I)=0.347$	Harris, 1963 [I—6]
Geometric albedo from rocket measurements in the ultraviolet	λ, Å / p_λ 2200 / 0.40 2360 / 0.50 2600 / 0.12 2750 / 0.35 3000 / 0.20	Stecher, 1965 [III—107]
Reflectivity from rocket measurements in the ultraviolet	2700 / 0.26	Boggess and Dunkelman, 1961 [II—46]
Geometric albedo	λ Å / p_λ 4530 / 0.445 4350 / 0.565 4210 / 0.575 4130 / 0.572 4015 / 0.580 3935 / 0.607 3900 / 0.565 3790 / 0.396 3750 / 0.376 3650 / 0.330 3610 / 0.292 3560 / 0.278 3500 / 0.252 3460 / 0.238 3400 / 0.232 3350 / 0.300 3290 / 0.330 3225 / 0.340	Glushneva, 1964 [III—9]

THE SPHERICAL ALBEDO, PHASE INTEGRAL, AND PHASE FUNCTION /12

The spherical albedo is the ratio of the total luminous flux reflected in all directions to the total flux incident on the planet's surface.

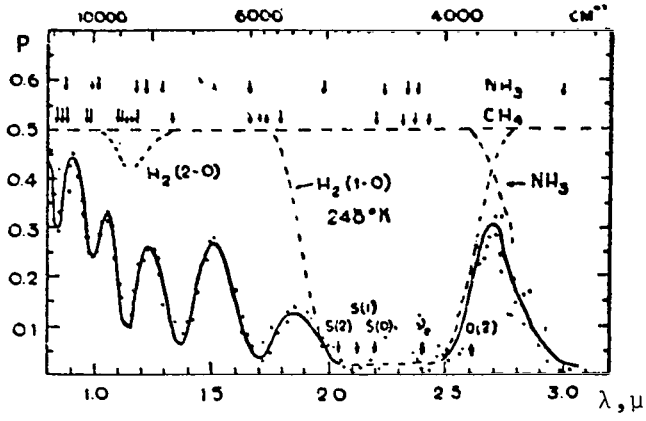


Figure 8. Infrared spectrum of Jupiter from balloon observations in the 0.8-3.1 μ region (according to Danielson).

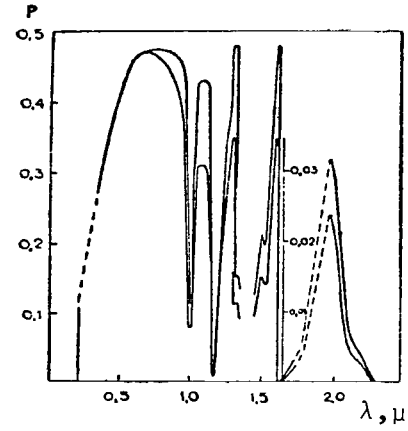


Figure 9. Limiting curves of Jupiter's monochromatic geometric albedo (according to Moroz).

$A_{sph} = p \cdot q$, where p is the geometric albedo and q is the phase integral. The exact value of q is not known.

The phase function, which represents the variation in the object's stellar magnitude with the phase angle α with other conditions unchanged, has been determined by Yu. V. Aleksandrov (1967 [II—6]). Jupiter's phase angle varies from 0° to 11°.6. Therefore, the calculated phase function which is presented is only a certain approximation to a possible actual function.

MONOCHROMATIC VALUES OF THE BRIGHTNESS AND THE GEOMETRIC ALBEDO /13

(ACCORDING TO IRVINE ET AL., 1968 [II—74])

λ_{eff} Å	m (1,0)	p_λ
3147	−8,70±0,02	0,269
3590	−8,89±0,03	0,320
3926	−9,02±0,02	0,361
4155	−9,10±0,02	0,387
4573	−9,26±0,02	0,450
5012	−9,34±0,01	0,484
6264	−9,48±0,01	0,551
7297	−9,18±0,01	0,418
8595	−8,86±0,01	0,311
10635	−8,85±0,01	0,308
U	−8,05±0,02	0,305
B	−8,54±0,02	0,422
V	−9,39±0,01	0,504

PHASE INTEGRAL AND SPHERICAL ALBEDO

Characteristic	Value	Author, Year
Phase integral, q	1.65	Harris, 1963 [I—6]
	1.50	Moroz, 1966 [III—17]
	1.16—1.18	Aleksandrov, 1965 [II—4, 5]
	1.6	Taylor, 1965 [III—111]
Spherical albedo, A_{sph}	0.73	Harris, 1963 [I—6]
	0.50±0.02	Moroz, 1966 [III—17]
	0.45	Taylor, 1965 [III—111]
	0.41-0.56	Russel, Stumpf, and Kuiper [I—12]

PHASE FUNCTION $\phi_{(\alpha)}$ [II—6]

α	$\varphi(\alpha)$	α	$\varphi(\alpha)$
0°	1,000	90°	0,329
15°	0,958	105°	0,227
30°	0,854	120°	0,149
45°	0,725	135°	0,084
60°	0,580	150°	0,035
75°	0,447	165°	0,010

SPECTRAL REFLECTIVITY

/14

Jupiter's geometric albedo in the ultraviolet, according to special observations from rockets, increases towards short wavelengths from 0.19 at λ 3000 Å to 0.38 at λ 2100 Å (Stecher, 1965 [III—107]) or remains approximately constant (around 0.2) between λ 3200 Å and λ 2200 Å, falling off sharply at λλ<2200 Å to ∿ 0.06 at λ 1800 Å (Anderson et al., 1969 [III—47a]).

The planet's reflectivity in the visual region of the spectrum increases with the wavelength according to the photometric measurements of G. Münch and R. Younkin (1963 [III—75*]).

*Translator's Note: Incorrectly cited as [74] in foreign text.

D. Taylor (1965 [III—111]) measured the absolute values of the monochromatic fluxes from Jupiter in the region from λ 3400 Å to λ 10000 Å. The reflectivity varies insignificantly with wavelength in the infrared region, but the methane absorption bands in this region cause deep depressions /15 in the spectral curve.

The results of the investigations enumerated are shown in Figures 10-13.

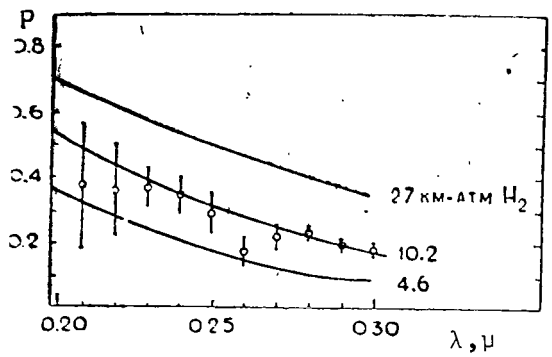


Figure 10. Jupiter's geometric albedo in the ultraviolet according to rocket measurement data. The lines represent the results of theoretical calculations of p(λ) for various amounts of H_2 (according to Stecher).

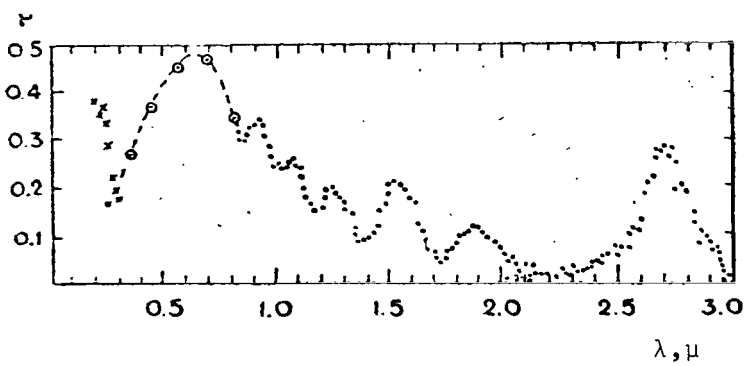


Figure 11. Combined curve of the dependence of Jupiter's geometric albedo on wavelength from the data of Stecher's measurements (crosses), Harris (open circles), and Danielson (dots).

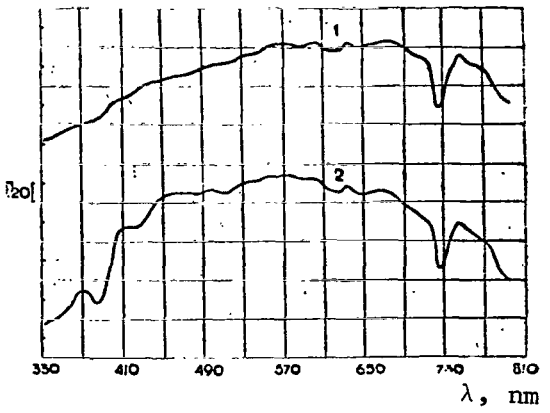


Figure 12. Curves of the spectral reflectivity (1) and the relative energy distribution (2) in Jupiter's spectrum (according to Münch and Younkin).

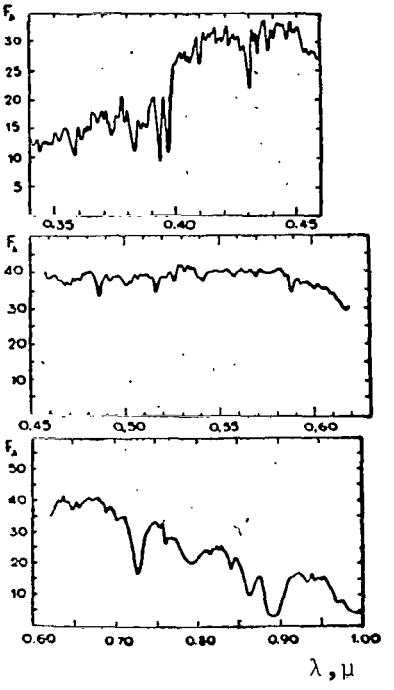


Figure 13. Absolute energy distribution in Jupiter's integral spectrum in the 0.35-1.00 μ region (according to Taylor). F_λ is the flux in units of 10^{-9} ergs/cm^2·sec·Å.

Some investigators have discovered a rather abrupt strengthening of the continuous absorption in Jupiter's spectrum at λλ 3500—4200 Å. Jupiter's reflectivity in the near ultraviolet is characterized by the spectrophotometric gradient

$$G_U = \frac{d \ln I_{\lambda J}/I^*_\lambda}{d\lambda^{-1}},$$

where $I_{\lambda J}$ is the planet's brightness and I^*_λ is the brightness of a comparison object.

Estimates of this quantity are presented in the following table:

Author, year	Date	λλ, Å	G_U	Comparison object
Kiess, Corliss, and Kiess, 1960 [III—68]	January, 1959	3700-4000	+7.38	Moon
Spinrad, 1962 [III—100]	April 28, 1961	to 3500	0	Moon
Teyfel', 1963 [III—26]	Sept. 13-14, 1962	3700-4100	1.11-1.25	Moon
Teyfel', 1963 [III—26]	Oct 11-12, 1962	3550-4100	1.68-1.77	Moon
Kartashov (unpubl).	Aug 28-29, 1964	3600-4200	0.59	β Tauri
	Aug 30-31, 1964	3600-4200	0.77	β Tauri
Kartashov, 1967 [III—13]	August, 1965	4500-4200	From 0.8 to 1.5	Sun

According to V. G. Teyfel' (1963 [III—26]) and V. V. Avramchuk (1966 [III—17]), the ultraviolet absorption is of a planetary nature, i.e., inherent in both the dark and bright belts.

MOLECULAR ABSORPTION BANDS IN THE SPECTRUM

At present the presence in Jupiter's spectrum of absorption bands has been firmly established for three gases which enter into the composition of this planet's atmosphere: methane (CH_4), ammonia (NH_3), and molecular hydrogen (H_2). The CH_4 and NH_3 bands are rotational-vibrational bands (overtones and combinations), and the H_2 bands are quadrupole bands induced by the pressure.

Methane.

Principal (fundamental) vibrational frequencies:

$\nu_1 = 2915\ см^{-1}$
$\nu_2 = 1520\ см^{-1}$
$\nu_3 = 3020\ см^{-1}$
$\nu_4 = 1306\ см^{-1}$

CH_4. THE VISUAL AND NEAR IR-REGION OF JUPITER'S SPECTRUM /17

λ, Å	Frequency interpretation	Eq. width, W, Å	λ, Å	Frequency interpretation	Eq. width, W, Å
5430	$7\nu_3$		8160	$5\nu_3-\nu_2$	
5760	$6\nu_3+\nu_4$		8430	$7\nu_4+\nu_3$	
6190	$6\nu_3$	16—23*	8610	$3\nu_3+\nu_1$	
6680	$5\nu_3+\nu_4$		8740	$9\nu_4$	
7020	$11\nu_4$	10—15	8360	$4\nu_3$	
7250	$5\nu_3$	87—105	9420	$6\nu_4+\nu_3$	
7820	$4\nu_3+\nu_2$		9800	$8\nu_4$	
7880	$10\nu_4$		9870	$3\nu_3+\nu_2$	
7980	$4\nu_3+\nu_4$		10090	$3\nu_3+\nu_4$	
8020	$5\nu_3-\nu_4$				

*The equivalent width is the same at various parts of Jupiter's disk.

CH_4. THE INFRARED REGION OF JUPITER'S SPECTRUM

λ, μ	Frequency interpretation	Eq. Width W, Å	Note
1.00	$2\nu_1+\nu_2+\nu_3$, $\nu_1+\nu_2+2\nu_3$	400	
1.094	$3\nu_3$	7	
1.15	$\nu_1+2\nu_3$, $3\nu_3$, $2\nu_1+\nu_3$ $2\nu_3+2\nu_4$, $2\nu_2+2\nu_4$	800	Blended with a telluric H_2O band at 1.13 μ
1.33	$\nu_2+2\nu_3$	200	Blended with a telluric band at 1.38 μ
1.47		250	
1.67	$2\nu_3$		
1.72	$\nu_1+\nu_2+\nu_4$, $\nu_2+\nu_3+\nu_4$		
2.20	$\nu_2+\nu_3$		
2.32	$\nu_3+\nu_4$		
2.38	$\nu_1+\nu_4$		
2.42	$\nu_2+\nu_4$		

The frequency interpretation (which is not uniquely possible) is given according to G. Herzberg, and the equivalent widths in the visual region of the spectrum are from the measurements of V. G. Teyfel', and from the measurements of V. I. Moroz [I—9] in the infrared region of the spectrum. Jupiter's spectrum in the infrared region is shown in Figure 14 (according to D. Cruikshank and A. Binder [III—53a]).

Ammonia. /18

The principal (fundamental) frequencies are:

$\nu_1 = 3337$ см$^{-1}$
$\nu_2 = 3415$ см$^{-1}$
$\nu_3 = 933$ and 967 cm^{-1}
$\nu_4 = 1628$ см$^{-1}$

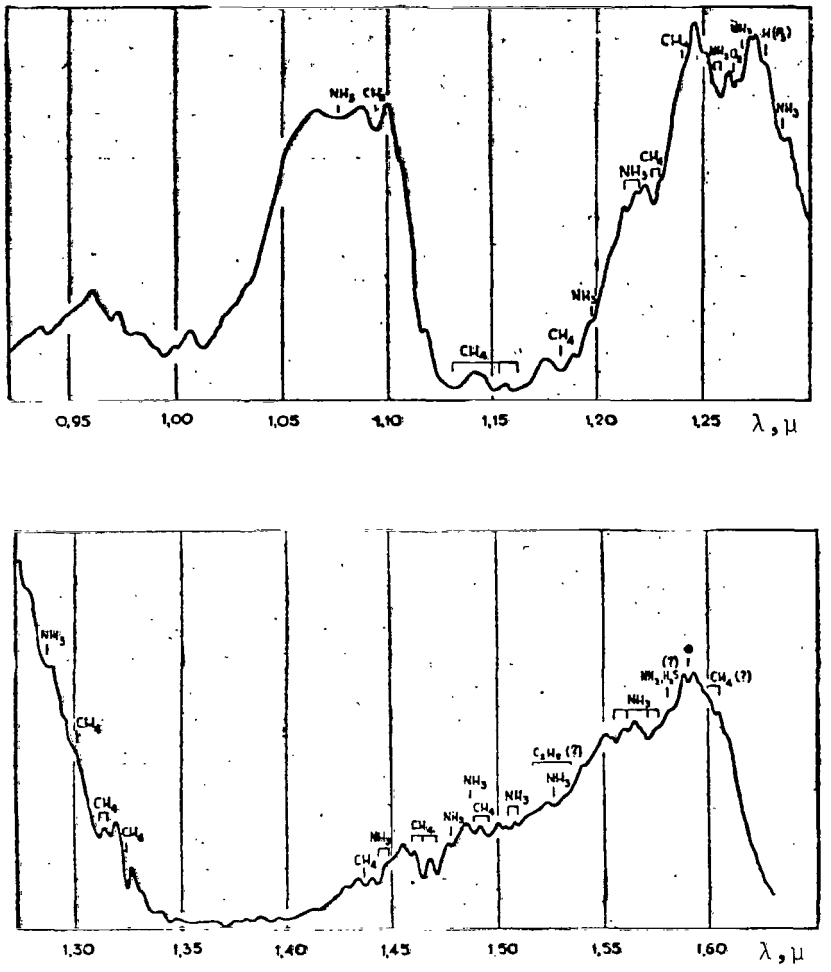


Figure 14. CH and NH_3 absorption bands in the near-infrared region 0.95–1.63 μ of Jupiter's spectrum (according to Cruikshank and Binder).

NH_3. ABSORPTION BANDS IN JUPITER'S SPECTRUM

λ, μ	Frequency interpretation	Eq. width, Å W, Å	Note
0,643 0,765	$5\nu_1$ $(4\nu_1+\nu_2)$	7.3	W-- according to Teyfel'. Discovered in 1964 (Owen, Richardson, and Spinrad [III--90])
0,793	$4\nu_1$ $(2\nu_1+2\nu_2)$ $3\nu_1+\nu_2$		
0,891	$\nu_1+2\nu_2$ $(3\nu_3)$		
0,990	$2\nu_1+\nu_4$		
1,23	$2\nu_2+\nu_4$	9	W-- according to Moroz [I-9]
1,26	$2\nu_1+\nu_3$	200:	"
1,31	$2\nu_1$ $(2\nu_3,\ \nu_1+\nu_3)$	250:	"
1,52		20	"
1,58	$\nu_2+\nu_3+\nu_4$		
1,67	$\nu_3+\nu_4$		
1,98	$\nu_2+\nu_3$		
2,25	$\nu_1+\nu_2$		
2,33 3,0		Absorption with solid ammonia is possible (observations from the balloon telescope "Stratoscope-2")	

Hydrogen.

Individual lines of the (4—0) and (3—0) quadrupole absorption bands of H_2 are observed in Jupiter's spectrum.

(4—0) QUADRUPOLE BAND OF H_2

Line designation	λ, Å	Integral absorption coefficient, S_0, $cm^{-1} km^{-1} atm^{-1}$
Q (1).	6565,0	$3{,}7\times10^{-5}$
S (0)	6435,0	$3{,}5\times10^{-5}$
S (1)	6367,8	$1{,}6\times10^{-4}$

The S (0) line is blended with an NH_3 adsorption band.

EQUIVALENT WIDTH OF THE S(1) LINE OF H_2 (4—0)

W, mÅ	Author, year
8±2	Spinrad and Trafton, 1963 [III—106]
6.5±2.5	Beckman, 1967 [III—48, 49]
8.5±1.5	Owen and Mason, 1968 [III—89]
9±2	Fink and Belton, 1969 [III—58a]
7.0±8.5(±2.0)	Emerson, Eddy, and Dulk, 1969 [III—56a]

(3—0) QUADRUPOLE BAND OF H_2 /20

Line designation	λ, Å	$S_{0'}$ $cm^{-1}km^{-1}atm^{-1}$
Q (1)	8497.52	4.2×10^{-4}
S (0)	8272.60	3.2×10^{-4}
S (1)	8150.66	1.3×10^{-3}
S (2)	8046.44	2.4×10^{-4}

EQUIVALENT WIDTHS OF THE LINES IN THE (3—0) BAND OF H_2

Author, year	S(1), mÅ	S(0), mÅ	Note
Kiess, Zabriskie, 1957 [III—125]	80	40	
Spinrad, 1962 [III—100]	40	31:	Central meridian
Spinrad, 1962 [III—100]	28	—	Equator
Tanaka, 1963 [III—109]			
Tanaka, 1963 [III—109]	55	39:	Center of the disk
	80	—	At a distance of 0.8 radii from the center on the equator
Owen and Mason, 1968 [III—89]	49±6		

INFRARED H_2 BANDS DISCOVERED IN 1963 FROM THE STRATOSCOPE-2 BALLOON TELESCOPE [III—54]

Designation	λ, μ	Note
H_2(2—0)	1.15	Weak, identification uncertain
H_2(1—0)	2.25	Strong, almost total absorption in the center of the band

SCHEMATIC DISTRIBUTION OF THE AMMONIA AND METHANE ABSORPTION IN THE ULTRAVIOLET AND INFRARED REGIONS (ACCORDING TO ÖPIK, 1962 [IV—93]) /21

Gas	λ, μ	Δλ, μ	Effective absorption cross section, cm^2
NH_3	0.139	0.018	4×10^{-19}
	0.155	0.014	5×10^{-20}
	0.165	0.005	4×10^{-19}
	0.173	0.012	6.2×10^{-18}
	0.184	0.011	3.1×10^{-18}
	0.199	0.018	1.2×10^{-18}
	0.212	0.007	4×10^{-19}
CH_4	0.137	0.01	1.5×10^{-18}
NH_3	1.6	0.4	4.5×10^{-23}
	9.75	0.66	5.3×10^{-20}
	10.65	0.38	1.3×10^{-19}
	11.55	0.28	1.3×10^{-19}
	12.65	0.88	6.7×10^{-20}
	18.4	2.0	3.2×10^{-21}
	30	20	1.2×10^{-22}
	50	20	6×10^{-22}
	70	20	3×10^{-21}
	90	20	1×10^{-21}
CH_4	1.2	0.3	6×10^{-24}
	7.7	1.0	4.1×10^{-21}
	44	20	5×10^{-27}

E. Öpik divided sections of the radiometric region (Figure 15) into a region with strong absorption (intense lines) and weak absorption, indicating respectively the effective extent of each region (Δλ). This table is suitable /22

DISTRIBUTION SCHEME FOR ABSORPTION BY METHANE AND AMMONIA IN THE RADIOMETRIC WINDOW (λλ 8—14 μ), ACCORDING TO ÖPIK (1962 [IV—93])

Molecule	Limits of λ, μ	Δλ, μ	Effective absorption cross section, cm^2 Strong absorption component	Weak component of the absorption
CH_4	8.0–9.2	0.20 1.00	4×10^{-21}	10^{-23}
NH_3	9.2–10.3	0.66 0.44	5.3×10^{-20}	$<3\times10^{-21}$
NH_3	10.3–11.0	0.35 0.35	1.3×10^{-19}	1.3×10^{-20}
NH_3	11.0–12.1	0.28 0.82	1.3×10^{-19}	$<3\times10^{-21}$
NH_3	12.1–13.2	0.88 0.22	6.7×10^{-20}	$<3\times10^{-21}$
NH_3	13.2–14.0	0.80		$\ll10^{-22}$

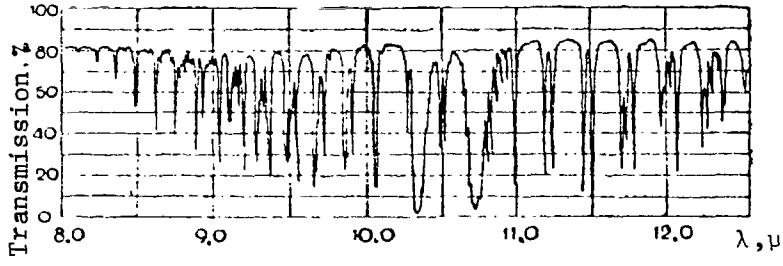


Figure 15. Laboratory spectrum of NH_3 in the 8-13 μ region according to Cross). The thickness of the gas layer in the cell was 10 cm.

for approximate calculations of the emergent thermal radiation from Jupiter's atmosphere in the range λλ 8—14 μ.

DISTRIBUTION OF THE INTENSITY OF MOLECULAR ABSORPTION ACROSS THE PLANET'S DISK

The investigation of the distribution of the intensity of the absorption bands across Jupiter's disk (also of the other giant planets) can give important information about the structure of the atmosphere and the cloud layer. The problem consists of the fact that the intensity of the absorption bands does

not follow the usual secant law, for which the intensity would increase towards the edges of the planet's disk in proportion to $\sec^n\vartheta$ (the secant of the zenith distance of the Sun and the observer).

Actually, the absorption either remains constant across the disk or decreases towards the edges. This situation must be associated with the fact that the planet's cloud layer is not a transparent screen but takes part in the formation of absorption lines and bands because of the effect of multiple scattering of light by the cloud particles and the absorption of quanta in a gaseous medium in which aerosols are suspended. The main results of measurements of the intensity of absorption bands in various parts of Jupiter's disk are presented below, based on observations made in various years. Judging from these data, the intensity and the variation across the disk vary somewhat with time.

6190 Å BAND OF METHANE, CH_4, HESS, 1953 (1949) [III—65] /23

Latitude, ϕ	Equivalent width of the band, W, Å	Number of measurements, n
0°	16,2±1,9	5
10°	13,7±1,4	4
30°	12,2±1,0	4
60°	13,9±2,2	8
Morning limb (E on eq.)	15,6±0,8	3
Evening limb (W on eq.)	15,3±1,4	3

TEYFEL', 1960 (1959) [III—22]

Region of the disk	Eq width, W, Å	Number of measurements, n
Northern temperate zone	18.4±1.7	66
Equatorial zone	18.0±1.8	65
Southern temperate zone	18.1±1.8	70

TEYFEL', (1962) [III—25]

Region of the disk	W, Å	n
Southern temperate zone	23.3±0.8	30
Southern tropical zone	22.3±0.9	29
Equatorial dark belt	23.7±0.9	29
Northern tropical zone	22.8±1.2	29
Southern part of the northern polar region	21.9±0.8	27

TEYFEL', 1964 (1963) [III—27]

Region of the disk	Limits, ϕ	W, Å	n
S-polar region	-50°--80°	19.5±0.4	17
S-temperate dark belt	-20°--30°	20.0±0.4	17
S-tropical zone	-10°--20°	18.5±0.4	17
S-part of the equatorial dark belt	0°--10°	20.4±0.4	17
N-part of the equatorial dark belt	0°-+15°	20.4±0.4	17
N-tropical zone	+15°-+25°	19.1±0.4	17
N-temperate zone	+25°-+35°	18.6±0.4	17
N-polar region	+50°-+80°	18.3±0.4	17

AVRUMCHUK, 1967 (1965—1966) [III—2]

/24

Period of the observations	W, Å	
	center of the disk	edge of the disk
January-February, 1965	23 - 25	14 - 15
October, 1965	27	12
March-August, 1966	17 - 19	13 - 14

According to Avramchuk, a rather strong decrease in the equivalent width of the 6190 Å band of CH_4 is observed towards the limb along the equator and towards the poles (Figure 16).

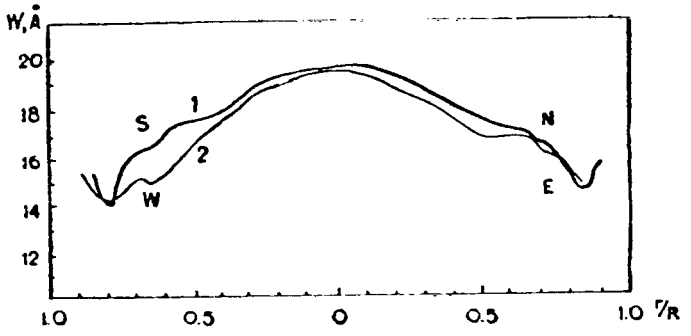


Figure 16. Variation of the equivalent width of the 6190 Å absorption band of CH_4 in Jupiter's spectrum along the central meridian (1) and the equator (2), according to Avramchuk.

INFRARED ABSORPTION BANDS OF CH_4

G. Münch and R. Younkin (1964 [III—75]) published in brief form the qualitative results of their own measurements of the distribution across Jupiter's disk of the absorption in the CH_4 bands in the λλ 7000—10000 Å region: the absorption increases with latitude in temperate latitudes and decreases abruptly towards the poles; it is stronger in bright zones than in the dark belts.

Similar data have been obtained by V. G. Teyfel' (1966—1967 [III—28]) from observations in 1964—1965 with an image converter. The distribution of the relative intensity at the center of the λλ 7250, 8860, and 9900 Å bands along Jupiter's equator and central meridian is illustrated in Figure 17. Photoelectric spectral measurements carried out by the same author in 1970 gave the following values for the equivalent widths (W) and the central depths (R) of the 7250 Å band of CH_4 on Jupiter's disk (see the table). /25

According to the measurements of M. Walker and S. Hayes (1967 [III—114]), the intensity of the lines in the 11000 Å band of CH_4 does not vary appreciably from the center of the disk out to 0.8 of the planet's radius.

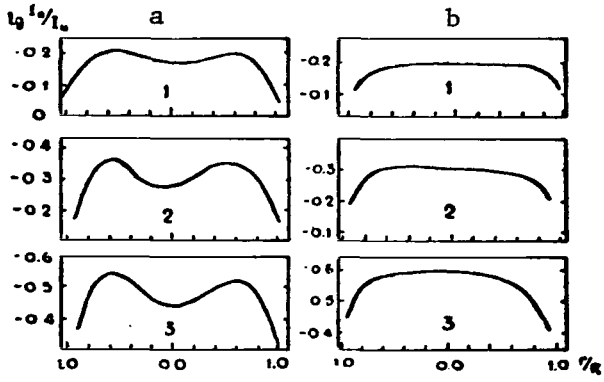


Figure 17. Variation of methane absorption across Jupiter's disk in the (1) 7250 Å, (2) 8860 Å, and (3) 9900 Å bands along the central meridian (A) and the equator (B), according to Teyfel'.

INTENSITY OF THE 7250 Å BAND OF CH_4 AT VARIOUS REGIONS OF JUPITER'S DISK

Zone of the disk	W, Å	R	Number of measurements, n
Central region	98±2	0.615±0.005	56
N-polar region	103±2	0.635±0.005	23
N-temperate zone	105±3	0.600±0.015	6
N-equatorial belt	97±2	0.605±0.005	11
S-temperate belt	96±2	0.610±0.010	7
S-temperate zone	100±2	0.625±0.005	10
S-polar region	99±3	0.635±0.010	24
W-limb	87±3	0.565±0.010	12
	92±2	0.620±0.005	43
E-limb	92±2	0.605±0.010	5
	92±2	0.620±0.005	52

G. Münch and R. Younkin (1964 [III—75]) employed spectral photoelectric observations and T. Owen (1969 [III—88a]) used photographic observations with interference filters to establish the presence of sharp maxima in the brightness of Jupiter's poles in the 8860 Å absorption band of CH_4. This phenomenon indicates the weakening of the absorption band, which is evidently associated with high cloud caps of the poles which are invisible in normal light. /26

6450 Å BAND OF AMMONIA, NH_3

HESS, 1953 (1949)[III—65]

ϕ	W, Å	n
0°	1.16±0.16	5
10°	1.08±0.30	4
30°	0.82±0.17	4
60°	0.98±0.13	8
E-limb	0.71±0.10	3
W-limb	1.10±0.30	3

AVRUMCHUK, 1968 (1963-1966) [III—1a]

Distance from the center of the disk in fractions of a radius	Equator (East - West)			Central meridian (north - south)		
	W, Å	σ	n	W, Å	σ	n
0.85	3.12	±1.33	7	3.02	±1.13	13
0.80	3.12	0.96	10	3.18	1.15	15
0.75	3.00	1.10	12	3.46	1.08	19
0.70	3.28	0.96	18	3.90	1.15	33
0.65	3.55	0.98	20	3.78	1.02	35
0.60	3.65	1.10	20	3.86	1.03	35
0.50	3.95	1.06	20	3.70	0.97	36
0.40	4.18	0.95	20	4.11	0.83	36
0.30	4.40	0.85	20	4.31	1.07	37
0.20	4.71	1.16	20	4.70	1.11	37
0.10	4.83	0.99	20	4.80	1.26	37
0.00	4.85	1.05	20	4.85	1.39	37
0.10	4.80	1.24	20	4.77	1.61	37
0.20	4.32	0.71	20	4.65	1.32	37
0.30	4.09	0.95	20	4.30	1.52	37
0.40	4.24	1.06	20	4.04	1.14	37
0.50	3.67	0.90	19	3.85	1.18	37
0.60	3.25	1.05	20	3.39	1.07	36
0.65	2.94	1.10	19	3.17	1.01	36
0.70	2.62	0.95	16	3.04	1.06	34
0.75	2.72	0.92	11	3.01	0.92	20
0.80	3.15	1.72	10	3.14	0.95	16
0.85	3.70	2.00	13	3.00	1.02	13

A. N. Aksenov (1969) [III—4a] did not find any kind of significant oscillations in the intensity of the 6450 Å band of NH_3 with time.

G. Münch and R. Younkin (1964 [III—75]) point out (without quantitative estimates) that the absorption is stronger in the 6450 and 7900 Å bands of NH_3 in the zones than in the dark belts and that the absorption at specified latitudes decreases toward the morning and evening limbs. /27

1.53 μ Band of Ammonia, NH_3

The intensity of the 1.53 μ band of NH_3 was measured by V. I. Moroz and D. P. Cruikshank (1969 [III—73a]) in various regions of Jupiter's disk. The band's width proved to be approximately 1.7 times greater at latitudes around 49° north and south of the equator than at the center of the disk. The ammonia absorption is less along the western (evening) limb than along the eastern (morning) limb. The absorption is weaker in the region of the Red Spot but weaker in the Southern temperate belt than in neighboring regions.

H_2(3—0) Band

According to the data of many investigators, the lines of this band do not change in intensity from the center to the edge of Jupiter's disk. Only V. Tanaka (1966 [III—109]) found that the S (1) line is strengthened with the transition from the center (W = 55—57 m Å) to the equatorial limb of the planet (W = 80 m Å). These results do not deserve special confidence, since they are based on measurements of only a single spectrogram.

A GENERAL SCHEME OF THE ATMOSPHERE'S STRUCTURE /28

A rigorous classification and nomenclature for the different layers has not yet been worked out for the atmospheres of the giant planets. Therefore, in the discussion of models for the atmospheres one usually employs that terminology which is used for the terrestrial atmosphere. Since the structure of Jupiter's atmosphere has yet been studied very poorly, the scheme presented for the structure of the atmosphere (Figure 18 and the table) is of a simplified nature. The numerical characteristics of the atmosphere's

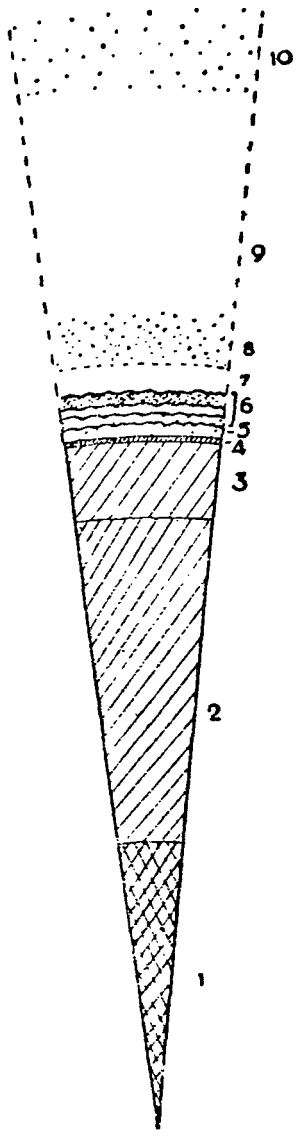


Figure 18. Schematic structure of Jupiter; 1) nucleus of heavy elements; 2) metallic hydrogen; 3) mantle (liquid or solid molecular hydrogen); 4) transition layer; 5) lower atmosphere (zone of high pressures); 6) convective zone (cloud layers); 7) outer atmosphere; 8) ionosphere; 9) thermosphere and exosphere; and 10) magnetosphere and radiation belts.

stratification (altitudes and the vertical extent of atmospheric layers) are still based only on the results of calculations of approximate theoretical models, since the observational estimates of these characteristics are lacking.

Zone	Layer	Methods of Study from the Earth
Magnetosphere	Radiation belts	Radio emission
Exosphere (optically ineffective)	Thermosphere Chemosphere Ionosphere	Theoretical calculations " " Radio emission
Outer atmosphere (optically effective)	Stratosphere (isothermal or with an inversion of the temperature)	Refraction effects, thermal emission
	Troposphere (adiabatic)	Scattering, absorption, and polarization of light; thermal emission
Convective zone	Outer cloud layer Lower cloud layer	Optical measurements Optical measurements (?), theoretical calculations
Lower atmosphere	Dry troposphere Region of high pressures	Theoretical calculations " "
Planet itself	Transition layer (solid or semi-liquid)	Theoretical calculations Radio emission (?)

CHEMICAL COMPOSITION OF THE OUTER ATMOSPHERE

Data about the chemical composition of Jupiter's atmosphere are based on a comparison of laboratory and observed data based on the intensity of

absorption bands of methane, ammonia, and hydrogen. In order to make quantitative estimates of the amount of these gases, one usually uses a simple /29
reflection model in which it is assumed that molecular absorption arises only in the outer atmosphere above the cloud layer, which plays the role of a reflecting screen. Since the absorption bands can actually be formed in the cloud layer by multiple scattering, the estimates of the gas content obtained from the simple reflection model should be considered as possible upper limits. Summaries are given below of the content estimates. Models of the atmosphere's chemical composition based on such estimates are presented in the next section.

MAIN CHARACTERISTICS OF THE GASES DETECTED IN JUPITER'S ATMOSPHERE

Gas	Molecular weight, μ	Melting point, °K (1 atm)	Boiling point, °K (1 atm)	Approximate density in the liquid phase	Approximate density in the solid phase
H_2	2,0	14	20	0,08	0,08
CH_4	16,0	89	112	0,42	—
NH_3	17,0	195	240	0,66	0,82

The gas content is determined numerically from the equivalent width of a uniform layer of it under normal conditions ($T = 300°K$, $P = 1$ atm) and is expressed in units of cm-atm or km-atm. 1 cm atm = 2.69×10^{19} molecules/cm^2.

Since a distinct inverse dependence is observed between the methane or /30
ammonia content obtained and the intensity of the absorption band, it is completely evident that the simple reflection model does not give correct results.

HYDROGEN, H_2

The difficulty in determining the hydrogen content in Jupiter's atmosphere from quadrupole lines is associated with the fact that they are very narrow and

METHANE, CH_4

Band λ, μ	Content, cm-atm	Author, year
0.6-0.9	$1.5 \cdot 10^4$	Kuiper, 1947 [I—19, 20]
"	$7.5 \cdot 10^3$	Moroz, 1966 (revaluation of Kuiper's data [III—17])
"	$(1.33 \pm 0.15) \cdot 10^4$	Owen, 1968 [III—88a]
1.10	10^4	Cruikshank and Binder, 1968 [III—53]
1.23	10^4	"
1.31—1.32	$2.5 \cdot 10^3$	"
1.33	$1.3 \cdot 10^3$	"
1.44	10^3–$2 \cdot 10^3$	"
1.47	$2 \cdot 10^3$–$6 \cdot 10^3$	"
1.10	$(6.2$–$8.1 \cdot 10^3$	Margolis and Fox, 1969 [III—71b]
1.10	$3 \cdot 10^3$	Belton, 1969 [III—49a]

AMMONIA, NH_3

Band λ, μ	Content, cm-atm	Author, year
0.195	0.3	Greenspan, Owen, 1967 [IV—53] from the rocket measurements of Stecher (1965 [III—107,108])
0.195	$2 \cdot 10^{-3}$	Anderson et al., 1969 [III—47a]
0.645	$7 \cdot 10^2$	Kuiper, 1947 [I—19, 20]
0.645	$1.2 \cdot 10^3$	Owen, 1968 [III—88a]
0.755	$2 \cdot 10^3$	Owen, Richardson, and Spinrad, 1964 [III—90]
1.26	$3 \cdot 10^2$	V. I. Moroz, 1966 [III—17]
1.52	$0.4 \cdot 10^2$	"
1.58	$2.5 \cdot 10^2$	"
3.0	$4 \cdot 10^3$–$4 \cdot 10^4$	Danielson, 1966 [III—54, 55]
1.8	$5 \cdot 10^2$	Cruikshank and Binder, 1968 [III—53]
1.22	$0.8 \cdot 10^2$	"
1.26	$2 \cdot 10^2$	"
1.29	$0.8 \cdot 10^2$	"
1.51	$0.2 \cdot 10^2$	"
1.53	$0.2 \cdot 10^2$	"
1.57	$4 \cdot 10^2$	"

subject to a contraction effect upon a pressure increase (see, for example, [III—58a]). These lines should be saturated in Jupiter's spectrum. Taking account of the saturation leads to significantly higher estimates of the H_2 content (noted in the table below by asterisks).

HYDROGEN, H_2

Absorption band or region of the continuous spectrum	Content, km-atm	Author, year
Continuous spectrum λλ 2000-3000 Å (Rayleigh scattering)	10.2±1.8	Stecher, 1965 (rocket measurements) [III—107, 108]
Continuous spectrum λλ 2000-3000 Å	12	Greenspan and Owen, 1967 (based on Stecher's data) [IV—53]
(4—0) 6368 Å	75±15	Emerson, Eddy, and Dulk, 1969 [III—56a]
(3—0) 8270 Å	4.6±0.6	Zabriskie, from Kiess' spectrograms, 1962 [III—125]
"	27±9	Spinrad and Trafton, 1963 [III—106]
"	270*	Foltz and Rank, 1963 (from Spinrad and Trafton's data) [III—59]
"	190*	Owen, 1965 (from Spinrad and Trafton's data) [III—83]
"	39*	Tanaka, 1966 [III—109]
"	110*	"
"	63-72*	Beckman, 1967 [III—48, 49]
"	68±14*	Beckman, 1967 (from Spinrad and Zabriskie's data) [III—48, 49]
"	85±15*	Owen and Mason, 1968 [III—89]
"	67±17*	Fink and Belton, 1969 [III—58a]
1.97 μ	30	Moroz, 1966 [III—17]

HYDROGEN, H_2 (Continued)

Absorption band or region of the continuous spectrum	Content, km-atm	Author, year
1.15 μ	45	Danielson, 1966 ("Stratoscope-2") [III—54, 55]
12-14 μ	12[1]	Gillette et al., 1969 [III—60a]

[1]Above the level with T = 125°K.

Concentrations higher than 100 km-atm are obviously unrealistic: in the case of such amounts of hydrogen the atmospheric pressure should be significantly higher than the observed pressure. Possibly the effective atmospheric mass in the line of sight is incorrectly taken into account.

OTHER POSSIBLE COMPONENTS OF THE ATMOSPHERE

Besides hydrogen, methane, and ammonia, which are detected directly from spectral observations, there may be other gases in Jupiter's atmosphere which do not reveal themselves in a spectral region which is accessible to observations, either because of the absence of absorption lines and bands or due to the extremely small amounts of such gases in the outer atmosphere. Data on /31 the average molecular weight of Jupiter's atmosphere ($\bar{\mu}>2$) point to the possibility of helium (He) being present. The upper limit of the estimates for the He content are about 40 km-atm, but values of about 15-20 km-atm are the most probable. T. Owen and H. Mason [III—89a] have found from the width of lines in the 6190 Å band of CH_4 that $H_2/He > 5$, i.e., that hydrogen predominates to a significant extent.

Thorough searches in Jupiter's spectrum for traces of the compounds presented below have not yet given positive results. T. Owen (1963, 1965, 1967 [III—81, 83, 87]) found upper limits for the content of some gases from a comparison of Jupiter's spectrograms with laboratory spectra.

More recently, D. Cruikshank and A. Binder (1969 [III—53, 53a]) derived such upper limits for the content of these gases in Jupiter's atmosphere from Jupiter's infrared spectrum and the laboratory spectra of a number of gases (see the table).

SOME GASES WHOSE PRESENCE IS POSSIBLE IN JUPITER'S ATMOSPHERE /32

Gas	Formula	Molecular weight, μ	Melting point, °K (1 atm)	Boiling point, °K (1 atm)	Approximate density	
					in the liquid phase	in the solid phase
Helium	He	4.0	—	4	0.15	—
Nitrogen	N_2	28.0	63	77	0.87	1.03
Oxygen	O_2	32.0	55	90	1.30	1.43
Neon	Ne	20.2	24	27	1.20	—
Argon	Ar	39.9	84	87	1.40	1.65
Water	H_2O	18.0	273	373	1.00	0.92

SOME CHEMICAL COMPOUNDS WHOSE PRESENCE IS POSSIBLE IN JUPITER'S ATMOSPHERE

Compound	Formula	μ	Melting Point, °K	Boiling point, °K
Hydrogen fluoride	HF	20.0	190	292
Hydrogen chloride	HCl	36.5	162	188
Hydrogen sulfide	H_2S	34.1	190	213
Hydrogen phosphide	PH_3	34.0	141	186
Acetylene	C_2H_2	26.0	—	189
Ethylene	C_2H_4	28.0	104	169
Ethane	C_2H_6	30.0	101	185
Silane	SiH_4	32.1	88	61
Carbon dioxide	CO_2	44.0	—	195
Hydrogen cyanide	HCN	27.0	259	289

UPPER LIMITS TO THE CONTENT OF THESE GASES (ACCORDING TO OWEN)

Gas	Band λ, Å	Limit to the content, cm-atm
C_2H_2	10372	$3 \cdot 10^2$
C_2H_4	8715	$2 \cdot 10^2$
C_2H_6	9060	$4 \cdot 10^2$
»	7415	$2{,}5 \cdot 10^2$
CH_3NH_2	10372	$3 \cdot 10^2$
»	9950	$8 \cdot 10^2$
CH_3D	9936	$2 \cdot 10^3$
HCN	10385	$2 \cdot 10^2$
SiH_4	9738	$2 \cdot 10^3$
HD	7377,7464	$5 \cdot 10^4$

UPPER LIMITS TO THE CONTENT OF THESE GASES
(ACCORDING TO CRUIKSHANK AND BINDER)

/33

Gas	Absorption band λ, μ	Limit to the content, m-atm
C_2H_2	1,538	0,04
CH_3NH_2	1,52	0,02
HCN	1,53	0,05
H_2S	1,58	0,25

On the basis of the absence of appreciable absorption in Jupiter's thermal infrared spectrum in the λλ 2.8—14 μ region, F. Gillette, F. Low, and W. Stein [III—60a] estimated the following upper limits to the concentration of certain compounds:

Gas	Absorption band λ, μ	Limit to the content, cm-atm
C_2H_2	13,7	0,5
C_2H_4	10,5	0,5
»	5,3	5
C_2H_6	12,2	3
CH_3NH_2	12,8	0,05
HCN	14	1
»	4,75	70
C_2N_2	4,7	2
SiH_4	10,5	1
PH_3	9,5	3
H_2S	8,0	300
CH_3D	8,6	6
	4,55	15

E. Lippincott, R. Eck, M. Dayhoff and C. Sagan (1967 [IV—76]) calculated the composition and content of all possible compounds of C, H, O, and N under the condition of thermodynamic equilibrium. Many compounds can be formed under the influence of electric discharges in the cloud layer (P = 1 atm, T = 1500°K) or in the thermosphere (P = 10^{-6} atm, T = 1000°K). The results of their calculations are presented in the table below.

/34

Molecules	Relative content in the mixture by volume			
	Clouds (1 atm, 200°K)	Deep layers (1000 atm, 350 °K)	Clouds (1 atm, 1500 °K)	Upper layers (10^{-6} atm, 1000 °K)
H_2	0,60	0,60	0,60	0,60
Inert gases	0,39	0,39	0,39	0,39
CH_4	$5\cdot10^{-3}$	$5\cdot10^{-3}$	$4\cdot10^{-3}$	$6\cdot10^{-5}$
NH_3	$2\cdot10^{-4}$	$2\cdot10^{-4}$	$2\cdot10^{-7}$	$2\cdot10^{-13}$
H_2O	$1\cdot10^{-6}$	$1\cdot10^{-4}$	—	—
H_2S	$1\cdot10^{-6}$	$1\cdot10^{-6}$	—	—
C_2H_2	—	—	$2\cdot10^{-4}$	$2\cdot10^{-8}$
C_2H_4	—	—	$3\cdot10^{-5}$	$7\cdot10^{-7}$
C_2H_6	$3\cdot10^{-23}$	$1\cdot10^{-15}$	$2\cdot10^{-7}$	$1\cdot10^{-2}$
HCN	0	0	$6\cdot10^{-5}$	$9\cdot10^{-5}$
CH_3CN	—	—	$6\cdot10^{-8}$	$2\cdot10^{-10}$
CH_3NH_2	$2\cdot10^{-31}$	$8\cdot10^{-21}$	—	—
NO_2	—	—	—	—
CH_3SH	$2\cdot10^{-28}$	$7\cdot10^{-20}$	—	—
CH_3OH	0	$3\cdot10^{-24}$	—	—
$(CH_3)_2SO$	0	$2\cdot10^{-29}$	—	—
CO_2	0	$1\cdot10^{-31}$	—	—
CO	0	$9\cdot10^{-32}$	—	—
HCHO	0	$2\cdot10^{-33}$	—	—
HCOOH	0	0	—	—
COS	0	0	—	—
Benzene	—	—	$2\cdot10^{-9}$	$1\cdot10^{-7}$
Naphthalene	—	—	$1\cdot10^{-12}$	$4\cdot10^{-9}$
Asphalt	—	—	$6\cdot10^{-25}$	$1\cdot10^{-8}$
Azylene	—	—	$5\cdot10^{-14}$	$2\cdot10^{-9}$
Aniline	—	—	$3\cdot10^{-19}$	$2\cdot10^{-23}$
Azobenzene	—	—	$3\cdot10^{-28}$	$3\cdot10^{-33}$

J. Greenspan and T. Owen (1967 [IV—54]) calculated the concentration of certain materials in chemical equilibrium at T = 298°K for a model of Jupiter's atmosphere based on a chemical composition similar to that of the Sun (see the table on page 35).

Material	Assumed initial content, cm-atm	Calculated equilibrium content, cm-atm	Note
H_2	$1{,}2 \cdot 10^7$	$1{,}2 \cdot 10^7$	
He	$2{,}35 \cdot 10^6$	$2{,}35 \cdot 10^6$	
Ne	$2{,}85 \cdot 10^3$	$2{,}85 \cdot 10^3$	
C	$1{,}26 \cdot 10^4$	0	*
O_2	$1{,}09 \cdot 10^4$	0	
N_2	$1{,}15 \cdot 10^3$	0	
Si	$7{,}6 \cdot 10^2$	0	*
Mg	$6{,}0 \cdot 10^2$	0	*
S	$4{,}8 \cdot 10^2$	0	*
Fe	$8{,}9 \cdot 10$	0	*
CH_4	0	$1{,}26 \cdot 10^4$	
NH_3	0	$2{,}3 \cdot 10^3$	
SiH_4	0	0	
SiO_2	0	$7{,}6 \cdot 10^2$	*
MgO	0	$6{,}0 \cdot 10^2$	*
H_2O	0	$1{,}98 \cdot 10^4$	
H_2S	0	$3{,}91 \cdot 10^2$	
FeS	0	$8{,}9 \cdot 10$	*

*In the solid phase at T = 298°K.

An extensive analysis of the possibility of the existence of different chemical compounds in Jupiter's atmosphere has been carried out by J. Lewis (1969 [IV—74a]).

MODELS OF THE ATMOSPHERE'S CHEMICAL COMPOSITION

Models of the chemical composition of Jupiter's atmosphere based not only on the observed data regarding the H_2, CH_4, and NH_3 content but also on indirect notions as to the relative amount of various gases, in particular, by analogy with the Sun's chemical composition or from data on the cosmic distribution of the elements, are used in theoretical calculations of a different nature.

Most often one attempts to select the relative content of the gases in Jupiter's atmosphere so as to obtain an average molecular weight $\bar{\mu}$ close to 3.3, which is the value found by W. Baum and A. Code (1953 [II—42]) from observations of Jupiter's occulation of the star σ Arietis. However, this value for $\bar{\mu}$ cannot be considered reliable, both because of insufficient accuracy /35

in the measurements and also because it is based on certain additional assumptions concerning the temperature of Jupiter's stratosphere.

MODELS OF THE RELATIVE CHEMICAL COMPOSITION (NUMBER OF MOLECULES, %)

Author, year	H_2	He	Ne	Ar	CH_4	NH_3	μ
Kuiper, 1952 [I—20] (a)	78.4	21.7	0.074	0.010	0.018	—	2.48
Kuiper, 1952 [I—20] (b)	38.5	61.2	—	—	0.28	—	3.26
Öpik, 1962 [IV—93]	2.3	97.2	0.39	0.042	0.63	0.0029	4.02
Spinrad and Trafton, 1963 [III—106]	60	36	3	—	<1	<1	3.4
Field, 1963 [summary in IV—74]	72.9	22.7	2.0	trace	2.0	0.3	3.1
Tanaka, 1966 [III—109]	38.9	60.8	0.19	—	0.15	—	3.3
Beckman, 1967 [III—48]	69.7	29.9	0.2	—	0.1	—	2.65
Moroz, 1967 [I—9]	73	26	—	—	0.05	—	2.6
Sodek, 1968 [IV—126]	44.83	53.95	0.22	0.01	0.26	0.08	3.16

As is evident, the main uncertainty in the models is associated with the /36 relative amount of the main constituents, namely, hydrogen and helium, on which the atmosphere's average molecular weight essentially depends. Another condition which the models of the chemical composition of the outer atmosphere should satisfy is the rather narrow range of possible values of the total pressure at the surface of the cloud layer (see the table).

Since the estimates of the atmospheric pressure based on the width of molecular absorption lines give values of about 1.5—2.5 atm, which leads to $P_0 \approx 1$ atm when account is taken of the role of multiple scattering in the cloud layer, preference should be given to models in which $P_0 \lesssim 2$ atm. Öpik's model, which has a very high (about 97%) helium content, clearly does not satisfy this condition.

MODELS OF THE OUTER ATMOSPHERE'S CHEMICAL COMPOSITION (CONTENT, cm-atm)

Author, year	H_2	He	Ne	Ar	CH_4	NH_3	P_0, atm
Kuiper, 1952 (b) [I—20]	$2.1 \cdot 10^6$	$3.3 \cdot 10^6$	—	—	$1.5 \cdot 10^4$	$7 \cdot 10^2$	2.0
Öpik, 1962 [IV—93]	$5 \cdot 10^5$	$2.1 \cdot 10^7$	$9 \cdot 10^4$	$1 \cdot 10^4$	$1.5 \cdot 10^4$	$7 \cdot 10^2$	11
Spinrad and Trafton, 1963 [III—106]	$2.7 \cdot 10^6$	$1.6 \cdot 10^6$	$7.0 \cdot 10^4$	—	$1.5 \cdot 10^4$	$7 \cdot 10^2$	1.6
Tanaka, 1966 [III—109]	$3.9 \cdot 10^6$	$6.1 \cdot 10^6$	$1.9 \cdot 10^4$		$1.5 \cdot 10^4$		3.5
Beckman, 1967 [III—48]	$7 \cdot 10^6$	$3 \cdot 10^6$	$2 \cdot 10^4$	—	$1 \cdot 10^4$	—	2.3
Moroz, 1967 [I—9]	10^7	$3.6 \cdot 10^6$	—	—	$7 \cdot 10^3$	$4 \cdot 10^3$	3.8
Moroz, 1967 [I—9]	$3.3 \cdot 10^6$	$1.5 \cdot 10^6$	—	—	$2.2 \cdot 10^3$	$1.5 \cdot 10^3$	1.3
McElroy, 1969 [III—71c]	$6.7 \cdot 10^6$	$<3.4 \cdot 10^6$	—	—	$4.5 \cdot 10^3$	$1.0 \cdot 10^3$	<3

RADIATION TEMPERATURE

The theoretically calculated radiation equilibrium temperature of the planet's surface depends on the distance of the latter from the Sun (on the value of the solar constant) and on the radiative peculiarities of the planet itself (absorption and reflection of solar radiation, the emission coefficient in the thermal region).

Solar Constant (for the Earth $S_0 = 1.98$ cal/cm^2·min)

At the average distance of Jupiter from the Sun (5.203 A.U.)	$S_J = 0.073$ cal/cm^2·min
At perihelion (4.953 A.U.)	$S_J = 0.081$ "
At aphelion (5.453 A.U.)	$S_J = 0.066$ "

T, °K	Author, year	Note
102	Kuiper, 1947 [I—19, 20]	For the visual albedo A = 0.51
105	Urey, 1959 [I—28]	For an albedo A = 0.47
105±3	Taylor, 1965 [III—111]	For the bolometric albedo A = 0.45 (λλ 3400-10,000 Å)
108±1	V. I. Moroz, 1967 [I—7]	For an albedo A = 0.50 ± 0.02 in the λλ 0.3—2.3 μ

RADIOMETRIC TEMPERATURE

Until recently Jupiter's temperature was determined from its thermal emission in the radiometric transparency window of the terrestrial atmosphere (λλ 8—14 μ). Since radiation in this region of the spectrum is strongly absorbed in the planet's atmosphere by ammonia, the observed values of T_B refer not to the visible surface of this planet but to some level of the atmosphere above the cloud layer, above which the equivalent thickness of NH_3 does not exceed 1 cm-atm.

MEASUREMENTS OF THE INTEGRAL BRIGHTNESS TEMPERATURE OF THE ENTIRE DISK AT λλ 8 - 14 μ

T_B, °K	Author, year	Radiation Receiver
130 ± 10	Coblentz and Lampland, 1926 (1924)	Thermocouple with a water filter
150	Pettit and Nicholson, 1924 [I—10]	Bolometer
131.5 ± 1.5	Sinton and Strong, 1960 (1952) [III—96a]	Thermocouple and a double monochromator
128 ± 2	Murray and Wildey, 1963 (1962) [III—78]	Germanium photoconductive cell alloyed with lead
128^{+5}_{-10}	Moroz, 1968 [III—18]	Silicon photoconductive cell cooled by liquid helium

MEASUREMENTS OF THE TEMPERATURE DISTRIBUTION
ACROSS JUPITER'S DISK AT λλ 8 - 14 μ

T_B at the center of the disk, °K	T_B at a distance of 60° from the center, °K	Author, year
128.5 ± 2.0	126 ± 0.5	Murray, Wildey, and Westphal, 1964 (1962) [III—79]
129	123	Wildey, Murray, and Westphal, 1965 (1963) [III—119]

The averaged map of the brightness temperature isophotes is presented in Figure 19. /38

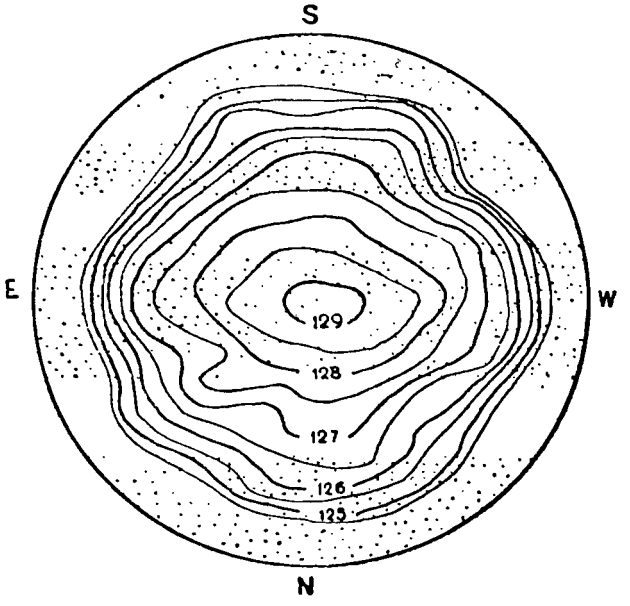


Figure 19. Averaged isophotes of the brightness temperature on Jupiter's disk from radiometric measurements at λλ 8—14 μ (according to Murray, Wildey, and Westphal).

DIFFERENCE IN THE TEMPERATURE OF INDIVIDUAL DETAILS FROM MEASUREMENTS AT λλ 8 - 14 μ (WILDEY, MURRAY, AND WESTPHAL)

Detail	$\bar{\Delta T}$	Year
Red Spot	-1.5- -2 °K	1963
Dark belts	+0.5 °K	1963
Dark and bright belts	0.1-0.9 °K	1965

MEASUREMENTS OF THE TEMPERATURE AT λ 20 μ

Author	Region of the disk	T
Low, 1966 [III—70]	Equatorial belt	150 °K
	Polar regions	130 °K

THE "HOT SHADOWS" EFFECT /39

In 1962 Murray, Wildey, and Westphal [III—79] discovered an abrupt temperature increase in the zone of the shadows cast by satellites on Jupiter's surface. However, although the authors assume this effect to be undoubtedly real, the observations during subsequent years led to negative results.

Shadow of satellite	Date	Number of measurements	Average brightness temperature of the shadow	
			Nucleus of the shadow (°K)	Entire shadow (°K)
J III	Dec. 26, 1962	1	184.5	155.5
J II	Dec. 15, 1962	3	191-196	164-164.5

In 1964-1965 the difference in the temperature of the planet's atmosphere in the shadow of satellites I, II, and III and outside it did not exceed several degrees.

Thus the radiometric measurements of Jupiter's brightness temperature in the λλ 8—14 μ region are in good agreement with each other and result in a /40 value for T_B of 128 ± 2°K for the center of the planet's disk. A decrease in the temperature towards the edges of the disk indicates a temperature gradient (a decrease with altitude) in the zone of the atmosphere which produces the effective thermal emission in this region. The "hot shadows" effect has not received a reliable explanation as of yet and is in need of additional verification.

RELATIONSHIP BETWEEN THE BRIGHTNESS TEMPERATURE AND THE RELATIVE VALUE OF THE THERMAL EMISSION FLUX IN THE RADIOMETRIC REGION λλ 8 - 14 μ (ACCORDING TO MURRAY, WILDEY, AND WESTPHAL, 1964)

T, °K	$\frac{F(T)}{F(273\ °K)}$	T, °K	$\frac{F(T)}{F(273\ °K)}$
100	$2{,}79\times10^{-4}$	155	$2{,}39\times10^{-2}$
105	$4{,}99\times10^{-4}$	160	$3{,}11\times10^{-2}$
110	$8{,}50\times10^{-4}$	165	$3{,}98\times10^{-2}$
115	$1{,}39\times10^{-3}$	170	$5{,}03\times10^{-2}$
120	$2{,}18\times10^{-3}$	175	$6{,}28\times10^{-2}$
125	$3{,}31\times10^{-3}$	180	$7{,}74\times10^{-2}$
130	$4{,}88\times10^{-3}$	185	$9{,}45\times10^{-2}$
135	$7{,}01\times10^{-3}$	190	$1{,}14\times10^{-1}$
140	$9{,}83\times10^{-3}$	195	$1{,}37\times10^{-1}$
145	$1{,}35\times10^{-2}$	200	$1{,}62\times10^{-1}$
150	$1{,}81\times10^{-2}$		

The value of the flux is normalized to the emission of an object with [T = 273° K].

RADIOMETRIC MEASUREMENTS IN THE λλ 1.5 - 330 μ REGION

Measurements of Jupiter's integral radiation flux, which were carried out in 1968 from an airplane at an altitude of 15 km (Aumann, Gillespie, and Low, 1969 [III—47b]) with the help of a germanium bolometer at λλ 1.5—330 μ gave the following results:

Flux	$(112\pm15)\ 10^{-13}$ watts/cm^2
Effective temperature	134±4 °K

SPECTRUM OF JUPITER'S THERMAL EMISSION AT λλ 2.8 - 14 μ

Spectral measurements of the thermal emission from Jupiter's entire disk (Gillett, Low, and Stein, 1969 [III—60a]) revealed a number of distinctive features (Figure 20):

1) the maximum of the emission is near λ 5 μ with a brightness temperature of 230°K;

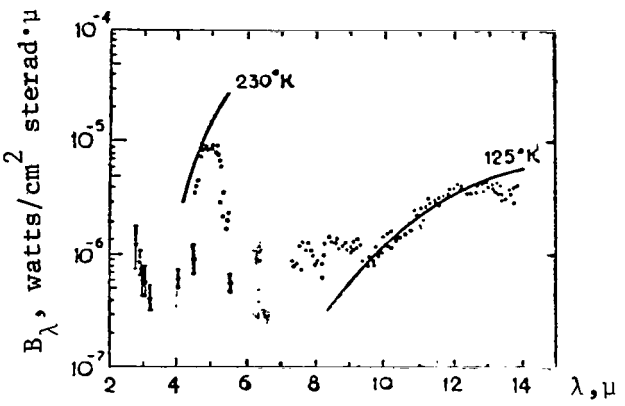


Figure 20. Spectrum of Jupiter's thermal emission at λλ 2.8—14 μ (according to Gillette, Low, and Stein). Sections of Planckian curves corresponding to temperatures of 230 and 125 °K are shown by solid lines.

2) increased emission (with T_B = 145°K) in the strong 7.7 μ band of CH_4, which indicates a temperature inversion in the upper atmosphere;

3) the spectrum of the thermal emission satisfies T_B = 125°K well in the λλ 9—13 μ region; and /41

4) There are a number of depressions in the emission corresponding to absorption bands of methane and ammonia.

ANOMALIES OF THE THERMAL EMISSION AT λλ 5 μ

J. Westphal (1969 [III—114a]) discovered an abrupt increase in the brightness temperature at λ 5 μ up to ∿ 235°K in Jupiter's northern equatorial belt with the temperature of other regions being $T \lesssim 210$°K. Brightness temperatures of up to 310°K were recorded in small dark sections of the northern hemisphere. No thermal anomalies were detected in the Red Spot.

ROTATIONAL TEMPERATURE

There have been several attempts at a spectroscopic determination of the rotational temperature of Jupiter's atmosphere on the basis of the relative intensity of rotational lines in the absorption bands. The results are still only of a tentative nature, and their use in calculations is not recommended, especially as it is still not clear, because of the effect of multiple scattering in the cloud layer, to what level the temperature refers.

SUMMARY OF DETERMINATIONS OF THE ROTATIONAL TEMPERATURE

Molecule, band (Å)	T_{rot}, °K	Author, year
H_2 (3-0) λ8270	170	Zabriskie, 1962 [III—125]
H_2 (3-0) λ8270	120-170	Spinrad and Trafton, 1963 [III—106]
H_2 (3-0) λ8270	120	Spinrad, 1964 [III—102]
CH_4 ($3\nu_3$) λ11057	200±25	Owen, 1965 [III—83, 85]
CH_4 ($3\nu_3$) λ11057	Indeterminate — from 100 to 300 based on various lines.	Walker and Hayes, 1967 [III—114]
CH_4 ($3\nu_3$) λ11057	180±20	Owen and Woodman, 1968 [III—92]
CH_4 ($3\nu_3$) λ11057	196-249 (±20)	Margolis and Fox, 1969 [III—71a, 71b]
CH_4 ($3\nu_3$) λ11057	163±20	Belton, 1969 [III—49a]

BRIGHTNESS TEMPERATURE IN THE RADIO REGION

Only the results of measurements of Jupiter's brightness temperature based on its radio emission in the millimeter and centimeter regions, where the non-thermal component of the radio emission still plays an insignificant role, are presented here. At $\lambda > 5$ cm, the planet's brightness temperature abruptly increases with wavelength, reaching tens of thousands of degrees at $\lambda > 50$ cm (see below). One should consider the measurements in the region of the spectrum where the nonthermal component is practically absent, i.e., at $\lambda < 3$ cm, to be the most reliable estimates of the temperature. /42

MEASUREMENTS OF T_B IN THE 0.3 - 2 cm REGION

λ	T_B, °K	Author, year
2.25 mm	180±60	Yefanov et al., 1969 [V—2a]
3.2 mm	111 (+22, -11)	Tolbert, 1966 [V—215]

MEASUREMENTS OF T_B IN THE 0.3 - 2 cm REGION (Continued)

λ	T_B, °K	Author, year
4.3 mm	105 (+18, -12)	Tolbert, 1966 [V—215]
8.35 mm	144±23	Thornton and Welch, 1963 (1962) [V—211]
8.6 mm	113±11	Tolbert, 1966 [V—215]
1.18 cm	123±8	Staelin and Neal, 1966 [V—206]
1.28 cm	116±8	"
1.35 cm	98±10	"
1.43 cm	106±10	"
1.53 cm	150	Welch, Thornton, and Lohman, 1966 (1964) [V—231]
1.58 cm	105±20	Staelin and Neal, 1966 [V—206]
1.6 cm	165±16	Vetukhnovskaya, Kuz'min et al., 1963
Average	123° K	

MEASUREMENTS OF T_B IN THE 3 cm REGION

λ, cm	T_B, °K	Author, year
3.02	185±20	Pariyskiy et al., 1964 [V—14]
3.03	171±20	Giordmaine et al., 1959 [V—113]
3.15	140±38	Mayer et al., 1958 [V—149]
3.15	145±18	Mayer et al., 1958 [V—149]
3.15	165±20	Alsop et al., 1958 [V—16a]
3.17	173±20	Giordmaine et al., 1959 [V—113]
3.3	193±16	Bibinova, V. P., et al., 1962 [V—1]
3.36	189±20	Giordmaine et al., 1959 [V—113]
3.75	140	Haddock and Dickel, 1963 [V—121]
3.75	200	Drake and Ewen, 1958 [V—85]
Average	170° K	

The radio emission flux in the 3 cm region at a distance of 4.04 A. U. is $F_\nu \simeq (1.2 - 2.5) \cdot 10^{-25}$ watt/m^2·hertz.

The pressure in the planet's atmosphere can be determined from the Lorentz width of molecular absorption lines. One usually uses the model of simple light reflection from the cloud surface. In the Curtis-Godson approximation, according to which the pressure at the atmosphere's base P_0 is equal to twice the value of the effective pressure determined from the line widths, the observed effective value P_{eff} refers to some level of the atmosphere above the cloud layer. But if the absorption lines are formed mainly inside the cloud layer, then P_{eff} will now refer not to a supra-cloud but to an intra-cloud zone of the atmosphere. In this case, the pressure at the surface of the clouds P_0 should not be greater but smaller than P_{eff}.

SPECTROSCOPIC ESTIMATES OF THE PRESSURE IN THE SIMPLE REFLECTION MODEL

Band, λ (A)	Half-width of the lines, $\Delta\nu$ cm^{-1}	P_{eff}, atm	P_0, atm	Author, year
CH_4 6190	<0,08	<1,4	<2,3	Spinrad and Trafton, 1963 [III - 106]
CH_4 6190	<0,08	<1	<2	Moroz, 1967 [1-9] based on Spinrad and Trafton's data
NH_3 6450	0,4±0,1		2	"
CH_4 6190	0,06	1,16	2,3	Beckman, 1967 [III-49]
NH_3 6450			5±1,5	Owen, 1968*
CH_4 6190			2,6	"
CH_4 11057	0,18±0,04	2,3±0,5		Farmer, 1969 [III-57a]

*Lecture at the Symposium on the Physics of the Planets (Kiev, October, 968).

OPTICAL THICKNESS OF THE OUTER ATMOSPHERE

The optical thickness of the supra-cloud atmosphere in the continuum iepends on its chemical composition (mainly on the amount of H_2 and He — ;ases which have significantly different refraction and scattering coefficients) nd on the presence in the outer atmosphere of an aerosol component such as

dust. The observational estimates of the outer atmosphere's optical thickness are still extremely unreliable and do not permit giving a unique answer to the question of whether or not it is purely gaseous or contains an aerosol.

OBSERVATIONAL ESTIMATES OF τ_0 IN THE CONTINUOUS SPECTRUM

Effective wavelength, Å	τ_B	Author, year
3500	0.8-1.3	Van de Hulst, 1949 (Ph) [I—14]
3900 (R)	0.25	Öpik, 1962 (Ph) [IV—93]
4500	0.23	Öpik, 1962 (Ph) [IV—93]
4500 (R)	0.13	Öpik, 1962 (Ph) [IV—93]
4600 (R)	0.10-0.20	Aleksandrov, 1965 (Ph) [II—5]
5500	0.40-0.80	Gehrels and Teska, 1962 (P) [II—67]
5600 (R)	0.05±0.02(a)	Gehrels, Herman, and Owen, 1969 (P) [II—66a]
	0.6±0.2(b)	
	0.4±0.2(c)	
5890 (R)	0.02±0.05	Aleksandrov, Yu. V., 1967 (Ph) [II—6]
6480	0.20±0.80	Khodyachikh, M. F., 1965 (Ph) [II—34]
6480	0.27±0.06	" 1967 (Ph) [III—42]
6480 (R)	0.07±0.02	" 1967 (Ph) [III—42]

(R) refers to the optical thickness of a purely gaseous (Rayleigh) component of the outer atmosphere;

(Ph) refers to the photometric measurements;

(P) refers to the polarization measurements;

(a) equator; (b) N. polar region; and (c) S. polar region.

THEORETICAL OPTICAL THICKNESS OF THE OUTER ATMOSPHERE OF JUPITER FOR PURELY MOLECULAR SCATTERING WITH A UNIFORM ALTITUDE OF H = 16 km and P_0 = 1 atm

Relative content		Optical thickness τ_p	
$H_2(n-1=1{,}38\cdot10^{-4})$	$He(n-1=0{,}35\cdot10^{-4})$	λ 3500 Å	λ 6000 Å
1	0	0,256	0,030
1,5	1	0,126	0,015
1	1,5	0,078	0,009
1	3	0,050	0,006
1	40	0,018	0,002
0	1	0,016	0,002

MODELS OF THE OUTER ATMOSPHERE'S STRUCTURE

We understand by outer atmosphere that part of the supra-cloud atmosphere which can be investigated by the optical methods used to investigate refraction effects, scattering, polarization, and absorption of light. Radiometric methods, and to some extent the methods of radio astronomy, also provide information on properties of the outer atmosphere.

There are several models for the structure of the outer atmosphere which treat it as comprised of two main layers — an isothermal stratosphere, and an adiabatic troposphere lying above the clouds.

Observations by W. Baum and A. Code (1952) of Jupiter's occultation of the star sigma Arietis constitute the only information of this kind concerning the Jovian stratosphere. According to the theory of refractive attenuation of starlight, the change in starlight during occultation depends entirely on a single parameter which characterizes the planetary atmosphere — the height H of the uniform atmosphere above the eclipse level. In general behavior, the curve for fading of starlight coincided best with calculation at $H \underset{\sim}{\sim} 8.3$ km. However the starlight curve itself, which was plotted from the observations, is not adequately reliable, so that H could even be twice the indicated value.

Kuiper's Model (1952)

Kuiper [I - 20] proposed two models based on models (a) and (b) for the chemical composition of the atmosphere (see above). Model (a) results in a pressure at the surface of the cloud layer of P_0 = 24 atm, which disagrees completely with the observational data. The temperature distribution from model (b) is shown in Figure 21, and the model's parameters are presented in the table below.

PARAMETERS OF KUIPER'S MODEL (b)

Parameter of the atmosphere	Value
Equilibrium temperature	T_r = 102°K
Temperature of the isothermal stratosphere	T_s = 86°K
Average molecular weight	$\overline{\mu}$ = 3.26
Height of the tropopause above the cloud layer's surface	Z_T = 20.5 km
Adiabatic temperature gradient in the supra-cloud troposphere	Γ_a = 4.0°K/km
Temperature at the cloud layer's surface	T_0 = 168°K
Pressure at the cloud layer's surface	P_0 = 2 atm
Height of the effective emission level in the radiometric region (T = 132°K) (from the cloud layer's surface)	Z_r = 11 km
Scale height for the outer atmosphere	H_0 = 16.6 km

Öpik's Model (1962)

Assuming that Jupiter's effective temperature is equal to 130°K, E. Öpik [IV—93] carried out a revaluation of the temperature of the stratosphere and, accordingly, (using Baum and Code's results) its average molecular weight. Öpik's model is evidently the most reliable of all existent models, since it assumes a helium excess in Jupiter's atmosphere in the presence of a very small hydrogen content. The pressure of 10 atm at the cloud layer's surface /46 which was derived in this model contradicts the observational data.

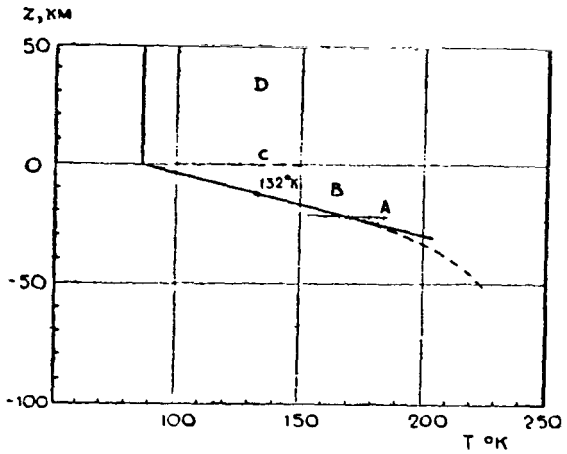


Figure 21. Temperature distribution in Jupiter's atmosphere according to Kuiper (model b): A is the cloud layer, B is the troposphere, C is the tropopause, and D is the stratosphere.

PARAMETERS OF ÖPIK'S MODEL

Parameter of the atmosphere	Value
Equilibrium temperature	$T_r = 130°K$
Temperature of the isothermal stratosphere	$T_s = 112 \pm 2°K$
Average molecular weight	$\frac{}{\mu} = 4.02$
Height of the tropopause above the cloud layer's surface	$Z_\tau \simeq 10$ km
Adiabatic temperature gradient in the supra-cloud troposphere	$\Gamma_a \simeq 4.7°K/km$
Temperature at the cloud layer's surface	$T_0 = 156°K$
Pressure at the cloud layer's surface	$P_0 = 10$ atm
Height of the effective emission level in the radiometric region	$Z_r = 5$ km
Scale height for the outer atmosphere	$H_0 = 13.4$ km

Gross and Rasool's Model (1964)

S. Gross and S. Rasool [IV—54] have calculated the temperature distribution in the outer atmosphere on the basis of the condition of radiative equilibrium (convective processes were not taken into account) for two models of the chemical composition:

I H_2 : He = 20 : (by volume),

II H_2 : He = 0,03 : (by volume).

The atmosphere was assumed to be gray, and the Eddington approximation was employed in the solution of the equation of radiative transfer /47

$$T^4(Z) = T_e^4\left(\frac{1}{2} + \frac{3}{4}\tau_z\right),$$

where T_e is the planet's effective temperature (T_e = 153°K) and τ_z is the average optical thickness in the infrared region above the level Z. The temperature distribution is shown in Figure 22.

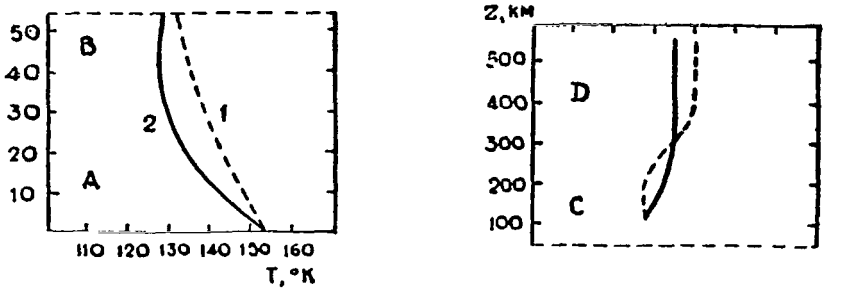


Figure 22. Temperature distribution in the troposphere and above the mesopause of Jupiter (according to Gross and Rasool). The calculations are for two models of the chemical composition: 1) H_2: He = 20:1, 2) H_2: He = 0.03:1 by volume. A is the troposphere, B is the stratosphere, C is the mesopause, and D is the mesosphere.

PARAMETERS OF GROSS AND RASOOL'S MODELS

Parameter of the atmosphere	I	II
Total optical thickness of the outer atmosphere at λλ 5—60 μ	$\tau_0 = 0.66$	$\tau_0 = 0.66$
Average molecular weight	$\frac{}{\mu} = 2.2$	$\frac{}{\mu} = 3.95$
Temperature gradient near the cloud layer	$\Gamma = 0.5$°K /km	$\Gamma = 1.1$°K/km
Temperature at the cloud layer's surface	$T_0 = 153$°K	$T_0 = 153$°K
Pressure at the cloud layer's surface	$P_0 = 3$ atm	$P_0 = 3$ atm
Height of the effective radiating level with T = 128°K above the cloud layer $\tau_r = 0$	$Z_r = 35$ km	$Z_r = 70$ km
Height of the mesopause (particle concentration of 3 X 10^{-14} cm^{-3})	$Z_M = 244$ km	$Z_M = 135$ km

PARAMETERS OF GROSS AND RASOOL'S MODELS (Continued)

Parameter of the atmosphere	I	II
Temperature of the isothermal atmosphere above the mesopause upon absorption of 50% of the Sun's ultraviolet radiation	T_c = 140°K	T_c = 135°K

Trafton's Model (1967)

L. Trafton [IV—131] proceeded from the following assumptions in calculating his model:

1) the main source of the atmosphere's thermal opacity is the pressure-induced dipole absorption of H_2 in a mixture with He; the absorption is partially produced by NH_3;

2) scattering in the thermal frequency region is insignificant, and the /48
emission function is Planckian;

3) the atmosphere is non-gray and optically thick in the thermal radiation region;

4) the effective temperature at a given latitude does not depend on the longitude;

5) the atmosphere is plane-parallel and is in thermodynamic equilibrium; and

6) radiative equilibrium is established in the upper atmosphere, and convective equilibrium — near the cloud layer; Trafton discussed pure hydrogen /49
models with various values of the effective temperature T_e and a model with a mixture of equal amounts of H_2 and He.

The temperature distribution with altitude is shown in Figure 23, and the spectral variation of the planet's monochromatic thermal emission fluxes

calculated by Trafton are shown in Figure 24.

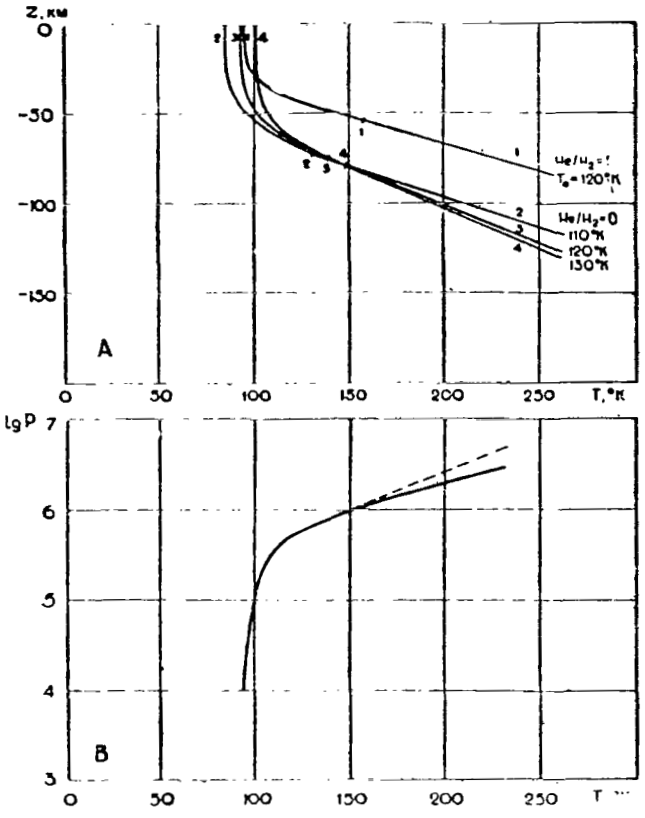


Figure 23. Trafton's models of Jupiter's atmosphere. A) temperature distribution in the convective zone and the stratosphere for four models. The short transverse dashes on curves 1—4 denote the boundary of the convective zone. B) the dependence between pressure and temperature for the model with T_e = 120°K and He/H_2 = = 0; the dashed curve takes convection into account.

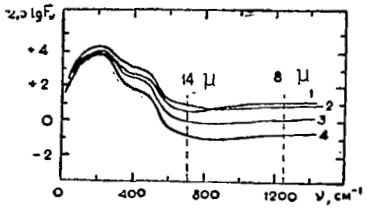


Figure 24. Spectral curves of the monochromatic fluxes of Jupiter's thermal emission according to Trafton's calculations for four models: 1) T_e = 120°K, He/H_2 = 1; 2) T_e = 130°K, He/H_2 = 0; 3) T_e = 120°K, He/H_2 = 0; 4) T_e = 110°K, He/H_2 = 0.

PARAMETERS OF TRAFTON'S MODELS

Parameter	I	II	III	IV
He/H_2	0	0	1	0
NH_3/H_2	0.0002	0.0002	0.0002	0.0002
CH_4/H_2	0.003	0.003	0.003	0.003
Effective temperature, T_e(°K)	130	120	120	110
Temperature of the isothermal stratosphere, T_s(°K)	100.5	93.6	95.5	85.3
Average optical depth of the convective zone's boundary	2.7	2.9	4.5	3.4
Temperature at the convective zone's upper boundary, T_0 (°K)	149	139	158	131
H_2 content above the convective zone (km-atm)	28	30	38	32
Temperature gradient in the convective zone, Γ_a(°K/km)	2.1	2.4	3.3	3.1

V. I. Moroz's Semi-Empirical Model (1967)

Specifying the chemical composition, temperature, and pressure at the cloud layer's surface and taking into account the contribution of multiple scattering to the intensity of molecular absorption bands, V. I. Moroz [I—7] calculated a model of the outer atmosphere (Figure 25), which includes, as do Kuiper's and Opik's models, a convective troposphere and an isothermal stratosphere. H is the scale height of a uniform atmosphere.

The average molecular weight is $\bar{\mu} = 2.6$; the temperature gradient in the troposphere is $\Gamma_a = 2.6$°K/km.

Lasker's Moist Adiabatic Model (1963)

B. Lasker [IV—74] calculated the temperature and pressure distribution with altitude in Jupiter's atmosphere, taking into account the saturation and

STRUCTURE OF THE ATMOSPHERE ACCORDING TO MOROZ'S MODEL

/50

Z, km	T, °K	P, atm	H, km	Amount (cm-atm) above the level, Z				Note
				H_2	He	CH_4	NH_3	
0	170	1,3	22	$3,3 \cdot 10^6$	$1,5 \cdot 10^6$	$2,2 \cdot 10^3$	$1,5 \cdot 10^3$	Surface of the cloud layer
15	127	0,57	16,5	$1,4 \cdot 10^6$	$7 \cdot 10^5$	$1 \cdot 10^3$	0,6	Level of effective emmision in the radiometric region
22	108	0,37	14	$9,4 \cdot 10^5$	$4,3 \cdot 10^5$	$6,2 \cdot 10^2$	$(2,5 \cdot 10^{-3})$	Level with radiation temperature
28	92	0,18	12	$4,6 \cdot 10^5$	$2,1 \cdot 10^5$	$3,0 \cdot 10^2$	$(6 \cdot 10^{-6})$	Tropopause
180	92	$5 \cdot 10^{-3}$	12	1,2	0,6	$(8,5 \cdot 10^{-4}$	$(2 \cdot 10^{-11})$	Occulation level

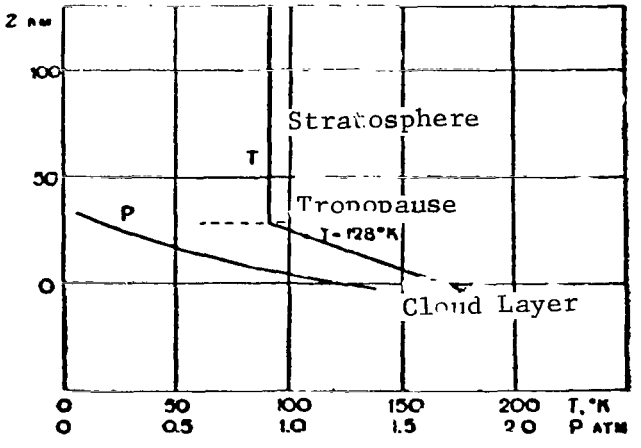


Figure 25. Temperature and pressure distribution in Jupiter's atmosphere (according to Moroz).

sublimation of NH_3. The calculations were carried out for the following values of the temperature at the lower sublimation level (the lower boundary of the clouds):

$$T_0 = 150, 160, 170, 180°K;$$

/51

for a relative NH_3 concentration

$$n_A = 0{,}00316;\ 0{,}010;\ 0{,}0316;\ 0{,}1;\ 0;$$

and a relative H_2 and He content of

$$H_2:He = 1:0,\ 1:1,\ 0:1.$$

In the case in which $n_{H_2} = n_{He}$, the following parameters for the sublimation level are obtained in the case of the two versions of the H_2 content:

Parameter	I	II
Average molecular weight, $\bar{\mu}$	3.3	3.3
Amount of hydrogen H_2, km-atm	5.5	8.5
Temperature at the sublimation level, T_s (°K)	163.6	164.2
Pressure at the sublimation level, P_s, atm	0.3	0.4
Relative ammonia concentration, n_A	0.0052	0.0037

If one assumes a hydrogen content of 27 km-atm, one obtains P_s = 1.9 atm and T_s = 166°K.

Lasker calculated the vertical temperature distribution above the sublimation level and the vertical pressure distribution as a function of temperature for various NH_3 (n_A) concentrations. The results of these calculations are shown in Figures 26 and 27. Depending on what height ΔZ above the sublimation level the reflecting surface of the clouds (from the depth of the cloud layer) /52 is located, the temperature at this level can vary by an amount $\Delta T_s = 2.3\ \Delta Z$ (°K/km) for $n_A = 0.005$.

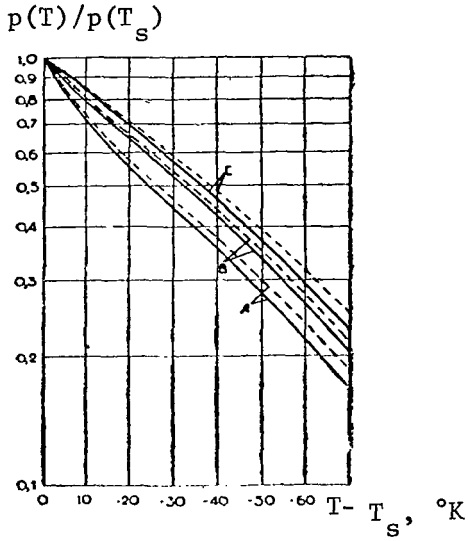


Figure 26. Variation in the relative pressure as a function of temperature in Jupiter's atmosphere above the sublimation level (according to Lasker). The solid curves are for T_s = 160°K, and the dashed curves are for T_s = 170°K. The relative concentration of ammonia (n_A) is: A) 0.01; B) 0.00316; and C) 0.000.

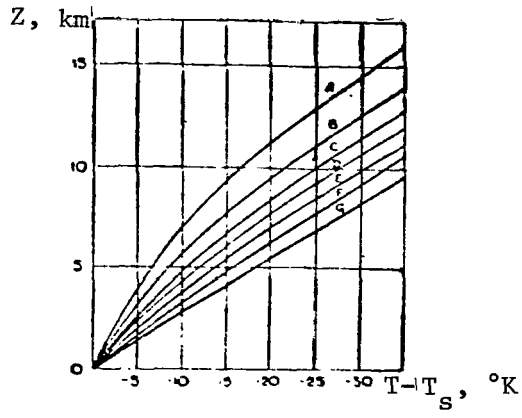


Figure 27. Variation in the temperature with altitude in Jupiter's atmosphere above the sublimation level (according to Lasker) for $\bar{\mu}$ = 3.3, T_s = 160°K, at a relative ammonia concentration (n_A) of: A) 0.015; B) 0.010; C) 0.007; D) 0.005; E) 0.003; F) 0.001; and G) 0.000.

The moist adiabatic temperature gradient in Jupiter's troposphere is approximately two times less than the dry adiabatic gradient in the case of the maximum NH_3 concentration (n_A = 0.015). As the concentration of NH_3 decreases, the temperature gradient Γ becomes equal to the dry adiabatic gradient. In the case of the maximum NH_3 concentration, such equality is attained at an altitude of about 12 km above the sublimation level. This fact indicates that the thickness of the cloud layer can be no greater than 15 km.

Hogan, Rasool, and Encrenaz's Models (1969)

J. Hogan, S. Rasool, and T. Encrenaz [IV—66a] have calculated temperature profiles of Jupiter's atmosphere, taking into account the possible heating of the upper atmosphere due to absorption of solar radiation in the 3.3 μ band of /53 CH_4. The relative amount of gases by volume in the five models calculated was assumed to be identical. Only the pressure and the temperature at the surface of the lower cloud layer (P_{H_2} = 2 - 6 atm, T_0 = 210 - 230° K) were varied. The best agreement with the observed spectrum of Jupiter's thermal radiation [III—60a] was exhibited by the theoretical calculations of the thermal spectrum based on model 3. The parameters of this model are presented in the table, and the temperature, density, and pressure curves are shown in Figure 28.

Parameters of Model 3

Parameter	Value
Amount of gas above the reference level:	
H_2	150 km-atm
He	30 km-atm
CH_4	150 m-atm
NH_3	21 m-atm
Temperature of the reference level	220°K
Total pressure at this level	5.6 atm
Average molecular weight	2.35
Adiabatic temperature gradient	2.25°K/km

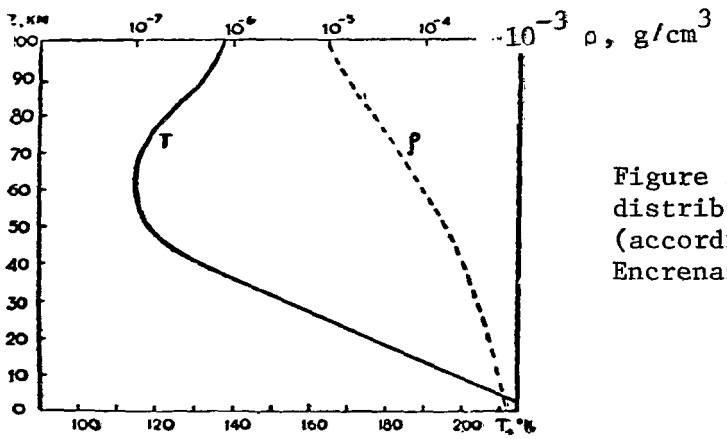


Figure 28. Temperature and density distribution in Jupiter's atmosphere (according to Hogan, Rasool, and Encrenaz).

DISTINCTIVE FEATURES OF THE ALTITUDE DISTRIBUTION OF THE NH_3 CONTENT

In contrast to the gas components (CH_4, H_2, He) which are uncondensed under the conditions of the outer atmosphere, ammonia can achieve a state of saturation at the observed total content and temperatures. Therefore, the concentration of gaseous NH_3 will not exceed the amount which corresponds to the saturation temperature at the given level, since the excess amount of ammonia passes into the liquid or solid phase. /54

PARTIAL PRESSURE AND TOTAL AMOUNT OF NH_3 ABOVE THE LEVEL AND THE SPECIFIED TEMPERATURE AND TEMPERATURE GRADIENT IN THE CASE OF SATURATION (MOROZ, 1967 [I—7])

T, °K	P_{NH_3}, mb	Amount of NH_3 (cm-atm) in the case of the gradient $\Gamma = -\frac{dT}{dZ}$ (°K/km)				
		0,4	1	2	2,8	4
100	$6 \cdot 10^{-7}$	$1{,}2 \cdot 10^{-3}$	$4{,}7 \cdot 10^{-4}$	$2{,}4 \cdot 10^{-4}$	$1{,}7 \cdot 10^{-4}$	$1{,}2 \cdot 10^{-4}$
127	$2 \cdot 10^{-3}$	6,2	2,0	1,0	$6{,}8 \cdot 10^{-}$	$5 \cdot 10^{-1}$
150	0,16	$7{,}0 \cdot 10^{2}$	$2{,}9 \cdot 10^{2}$	$1{,}4 \cdot 10^{2}$	$1{,}0 \cdot 10^{2}$	$7 \cdot 10^{3}$
170	4	$1{,}45 \cdot 10^{4}$	$5{,}9 \cdot 10^{3}$	$2{,}9 \cdot 10^{3}$	$2 \cdot 10^{3}$	$1{,}4 \cdot 10^{3}$
200	80	$3{,}6 \cdot 10^{5}$	$1{,}42 \cdot 10^{5}$	$7{,}2 \cdot 10^{4}$	$4{,}85 \cdot 10^{4}$	$3{,}6 \cdot 10^{4}$

OPTICAL PROPERTIES OF CLOUD DETAILS

The albedo and color of the dark and bright belts and individual details on Jupiter are subject to significant variation with time. Therefore the tables presented here of the relative intensities and brightness coefficients of various cloud features reflect the state of Jupiter's visible surface only at the corresponding period of the observations. However, these data can characterize the range of the variations in the optical properties of the cloud cover which occur on the planet.

CONTRASTS ON THE PLANET'S DISK ACCORDING TO V. N. LEBEDINETS (1957 [II—26]) RELATIVE INTENSITY OF BRIGHT AND DARK BELTS (WITH RESPECT TO THE MOST DISTINCT BRIGHT ZONE)

Year of the observation	Light filter, λ_{eff}, nm	Southern bright belt	Southern dark belt	Equator	Northern dark belt	Northern bright belt
1933	Red, 652	0,918	0,980	1,000	0,830	0,901
	Yellow, 572	0,902	0,939	1,000	0,825	0,835
	Blue, 458	0,791	0,924	1,000	0,736	0,841
1935	Yellow, 572	0,992	0,808	1,000	0,823	0,961
	Blue, 458	0,956	0,770	0,926	0,825	1,000
1938	Red, 652	0,987	0,914	0,916	0,923	1,000
	Blue, 458	0,970	0,836	0,824	0,809	1,000

Year of the observation	Light filter, λ_{eff}, nm	Southern bright belt	Southern dark belt	Equator	Northern dark belt	Northern bright belt
1939	Red, 652	1,000	—	0,888	0,855	0,998
	Blue, 458	0,834	—	0,910	0,839	1,000
1953	Red, 648	0,881	0,851	1,000	0,833	0,915
	Yellow, 594	0,915	0,938	1,000	0,883	0,965
	Green, 521	0,979	0,899	1,000	0,836	1,000
	Blue, 452	0,960	0,818	1,000	0,851	0,883
1957	Red, 648	1,000	0,951	0,992	0,854	0,969
	Yellow, 594	1,000	0,926	0,997	0,824	0,960
	Green, 521	0,997	0,914	1,000	0,801	0,974
	Blue, 432	1,000	0,896	0,975	0,835	0,947

Below are presented the values of the brightness coefficients, which represent the ratio of the brightness of the surface in a given direction to the illumination of this surface.

RATIO OF THE INTENSITY OF THE EQUATORIAL DARK BELT AND THE BRIGHT TROPICAL ZONE OF JUPITER IN 1962-1965 ACCORDING TO V. G. TEYFEL' (1968) [II—30]

/55

Light Filter	λ_{eff}, nm	1962	1963	1964-1965
Red	625	0.85	0.89	0.94
Green	530	0.73	0.84	0.87
Blue	440	0.60	0.72	0.73
Violet	405	0.50	0.71	0.72

BRIGHTNESS COEFFICIENTS OF THE CENTRAL REGION OF THE BRIGHT EQUATORIAL BELT ACCORDING TO V. N. LEBEDINETS, 1957 [II—26]

Year	λ_{eff}, nm	r	Year	λ_{eff}, nm	r
1953	648	0,849	1954	648	0,872
	594	0,758		594	0,751
	521	0,673		521	0,731
	432	0,484		432	0,503

BRIGHTNESS COEFFICIENTS OF THE CENTRAL PORTION OF JUPITER'S DISK, ACCORDING TO M. F. KHODYACHIKH, 1967 [III—421*

Fall 1965				January — May 1966					
λ, nm	r_λ	λ, nm	r_λ	λ, nm	r_λ	λ, nm	r_λ	λ, nm	r_λ
440	0,718	530	0,753	400	0,403	490	0,691	580	0,860
450	0,686	540	0,710	410	0,443	500	0,705	590	0,863
460	0,664	560	0,731	420	0,481	510	0,710	606	0,852
470	0,708	570	0,748	430	0,520	520	0,717	610	0,860
480	0,769	580	0,757	440	0,560	530	0,750	630	0,860
490	0,787	590	0,741	450	0,603	540	0,784	640	0,859
500	0,793	600	0,719	460	0,643	550	0,810		
510	0,794	610	0,698	470	0,667	560	0,828		
520	0,789	630	0,700	480	0,676	570	0,844		

*The results for 1965, which give a practically neutral variation of Jupiter's reflectivity, seem doubtful.

ALBEDO OF THE DARK EQUATORIAL BELT IN 1962 /56

λ_{eff}, nm	Albedo	Author, year
Visual light	0.06-0.14*	Vsekhsvyatskiy, 1965 [II—20]
380	0.14	Kartashov, Teyfel', Usol'tseva, 1969 [II—21a]
440	0.24	
540	0.42	
620	0.44	

*Evidently a strongly understated value.

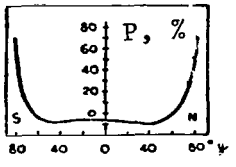


Figure 29. Variation in the degree of polarization with latitude along Jupiter's central meridian (according to Dollfus). The degree of polarization P is in units of tenths of a percent.

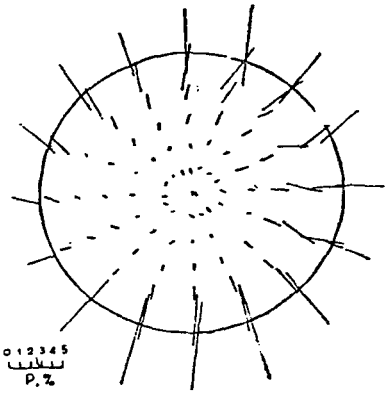


Figure 30. Distribution of the degree of polarization and the position of the electric vector's plane on Jupiter's disk in the ultraviolet (according to Hall and Riley).

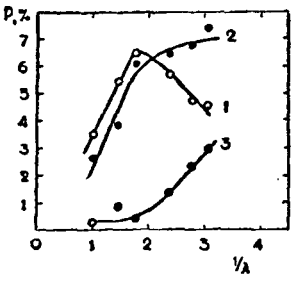


Figure 31. Wavelength dependence of the degree of polarization of the polar regions and the equatorial limb of Jupiter (according to Gehrels and Teske): 1) N. polar region; 2) S. polar region; and 3) E. limb.

ESTIMATES OF THE DEGREE OF POLARIZATION OF VARIOUS REGIONS OF JUPITER'S DISK /57

Author, year	Region of the planet	Degree of Polarization
Lyot, 1929 [I—7]	Center of the disk	Variation with phase angle from 0.6 to -0.1 %
	Belt	Up to 7%, does not depend on the phase angle
Dollfus, 1955 [I—7]	Central meridian	Constancy up to ±60° of latitude with P = -0.8% and a subsequent increase toward the poles up to 7% (Figure 29)
	Center of the disk at $\alpha = 11°.7$	-0.6%, does not depend on the wavelength
Gehrels, 1962 [II—67]	North Pole	Maximum polarization of 6.5%
	South pole	" 7.4%
	East limb	" 3%

ESTIMATES OF THE DEGREE OF POLARIZATION OF VARIOUS REGIONS OF JUPITER'S DISK (Continued)

Author, year	Region of the planet	Degree of Polarization
		Degree of polarization depends on the wavelength (Figure 31)
Bolkvadze, 1967 [II—16]	Integral (entire disk)	From 0.1 to 0.3%. No dependence on phase angle has been detected
	Center of the disk	From 0.70 to 1.75%. The polarization in the interval of phase angles from 3° to 7° is almost identical, and it begins to increase as the phase angle increases
	South Polar region	An increase from 8.2 to 9.4% in the range of phase angles 2°.6-6°.6, and the polarization subsequently drops sharply, reaching 4.9% at a phase angle of 9°.5.
	North polar region	A decrease from 2.4 to 1.8% for phase angles of 2°.6-9°.4
Hall and Riley, 1969 [II—70a]	Scanning across the disk	The polarization is radial, and it is a maximum at the poles, reaching 10% at λ 3760 Å (Figure 30)

BRIGHTNESS DISTRIBUTION ACROSS THE DISK

Investigation of the brightness distribution across the disk of a planet surrounded by a cloud layer offers the possibility of obtaining information

about the optical parameters of the cloud cover, since the albedo and limb darkening depend on the amount of pure absorption by the cloud particles and /58
on the scattering indicatrix.

Photometric measurements of the brightness distribution across Jupiter's disk and the disk's limb darkening have been carried out by many investigators, but photographic images of vary small diameters (from 0.8 to 5 mm) have been used in the majority of cases. The limb darkening along the equator varies comparatively little with wavelength and becomes less in the short-wavelength region. The brightness distribution along the central meridian depends strongly on wavelength and varies significantly with time, which reflects the variations in color and relative intensity of the dark cloud belts on Jupiter's disk. Curves of the variation of the relative intensity in red and blue light along the equator and the central meridian for different years are presented in Figures 32-36.

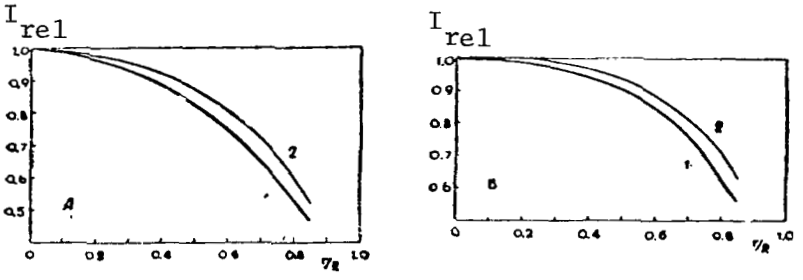


Figure 32. Variation of the relative intensity along Jupiter's equator (according to N. P. Barabashov). A) 1935: 1) in yellow light, 2) in blue light; B) 1938: 1) in red light, 2) in blue light.

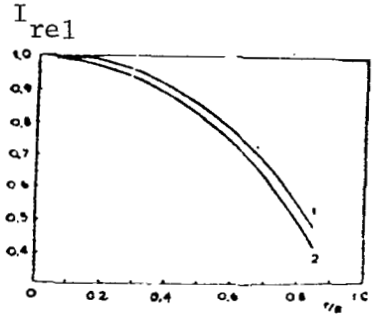


Figure 33. Variation of the relative intensity along Jupiter's equator in 1952 (according to V. N. Lebedinets): 1) in blue light, 2) in red light.

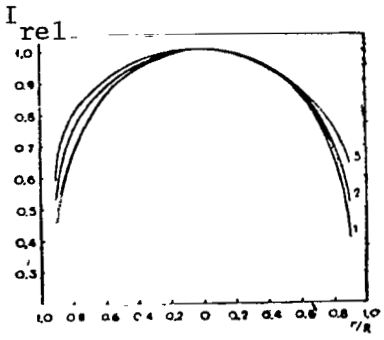


Figure 34. Variation of the relative intensity along Jupiter's equator in 1967 (according to V. F. Kartashov): 1) in orange light, 2) in blue-green light, and 3) in blue light.

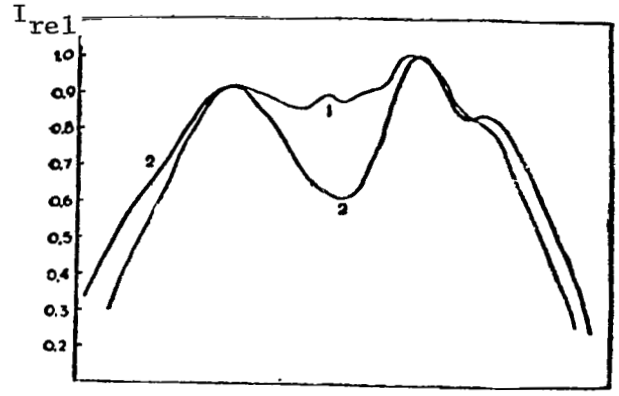


Figure 35. Variation of the relative intensity along Jupiter's central meridian in 1962 (according to V. G. Teyfel'): 1) in red light, 2) in blue light.

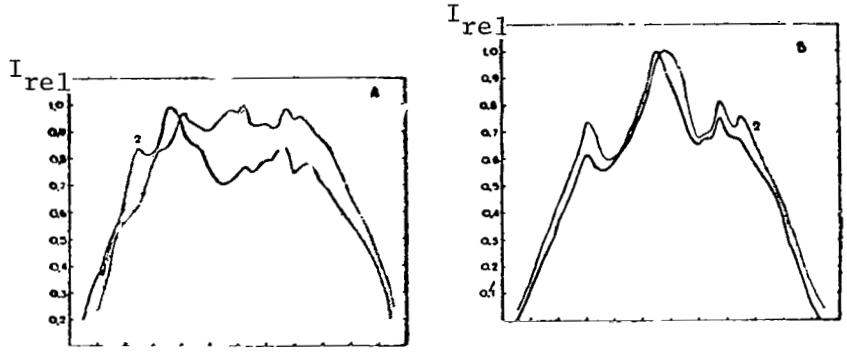


Figure 36. Variation of the relative intensity along Jupiter's central meridian (according to V. F. Kartashov). A) 1964: 1) in yellow light, 2) in blue light; B) 1967: 1) in yellow light, 2) in blue light.

SCATTERING INDICATRIX OF THE CLOUD LAYER /59

The scattering indicatrix is usually given in the form of a more or less simple function of the scattering angle γ. The parameters of such a function are determined from photometric measurements by comparing them with theoretical

calculations.

The spherical indicatrix has the form $X(\gamma) = 1$, and the simplest non-spherical scattering indicatrix is $X(\gamma) = 1 + X_1 \cos\gamma$. To obtain more prolate indicatrices, expressions of the form $X(\gamma) = 1 + X_1 P_1(\cos\gamma) + X_2 P_2(\cos\gamma)$, where P_1, P_2 are Legendre polynomials, are applied.

OBSERVATIONAL ESTIMATES OF THE SCATTERING INDICATRICES PARAMETERS /60

Author. year	Form of the indicatrix	λ_{eff}, nm	Value X_1	Value X_2	Note
Lebedinets, 1952 [II—25]	Arbitrary		$X(\pi)=0,1$		According to Barabashov's data
"					
Lebedinets, 1957 [II—26]	$1+X_1\cos\gamma$		0,2		1951-1954
	$1+X_1\cos\gamma$		0,9		
Aleksandrov, 1965 [II—4]	$1+X_1\cos\gamma$	652	$0,55\pm0,70$		Bright equatorial belt (1935)
		578	$-1,01\pm0,21$		
Aleksandrov, 1965, 1967 [II—5, 6]	$1+X_1P_1(\cos\gamma)+X_2P_2(\cos\gamma)$	460—650	1,36	$0,5+0,25X_1$	Bright zones
			1,29	$0,5+0,25X_1$	Dark belts
Harris, 1963 [I—6]	$1+X_1\cos\gamma$	540	0,6		
Avramchuk, 1968 [III—4]	$1+X_1P_1(\cos\gamma)+X_2P_2(\cos\gamma)$		$2,50<X_1<2,60$	$3,10<X_2<3,54$	Based on the 6190 Å absorption bands of methane, CH_4

SINGLE-SCATTERING ALBEDO OF THE CLOUD LAYER PARTICLES

The single-scattering albedo $\omega_н = \frac{\sigma}{\sigma+\varkappa}$, where σ is the scattering coefficient and $\varkappa$ is the pure absorption coefficient, represents an important characteristic of the cloud medium on a planet.

The quantity ω is determined from photometric measurements by comparing them with theoretical calculations of the albedo and the limb darkening of the planet's disk, which are carried out for specific assigned scattering indicatrices (see the table below).

OBSERVATIONAL ESTIMATES OF ω_H

Author, year	λ_{eff}, nm	Zone of the planet	ω_H
Lebedinets, 1952 [II—25]		Equator	0.992
Harris, 1963 [I—6]			0.98
Aleksandrov, 1965 [II—4]	460-650	Bright zones	0.987±0.003
		Dark belts	0.980±0.004
	430	Bright zones	0.984±0.988
		Dark belts	0.977±0.982
Aleksandrov, 1965 [II—5]	652-578	Equator	1.000±0.001
			0.985±0.012
Aleksandrov, 1967 [II—6]	430	Bright zones	0.974-0.984
		Dark belts	0.982-0.990

THE STRUCTURE AND COMPOSITION OF THE CLOUD LAYERS

Jupiter's cloud cover is evidently entirely opaque for direct solar radiation and most likely consists of several layers with different vertical /61
structure and chemical and phase composition. It appears most probable that at least the visible part of the cloud cover is formed mainly by ammonia crystals. The existence of cloud layers of ice and droplets of H_2O or of other chemical compounds is assumed in the deeper zones of the atmosphere. According to the theoretical calculations of J. Lewis [IV—74b], the structual layout of the aerosol component of Jupiter's atmosphere may be rather complicated, as shown in Figure 37.

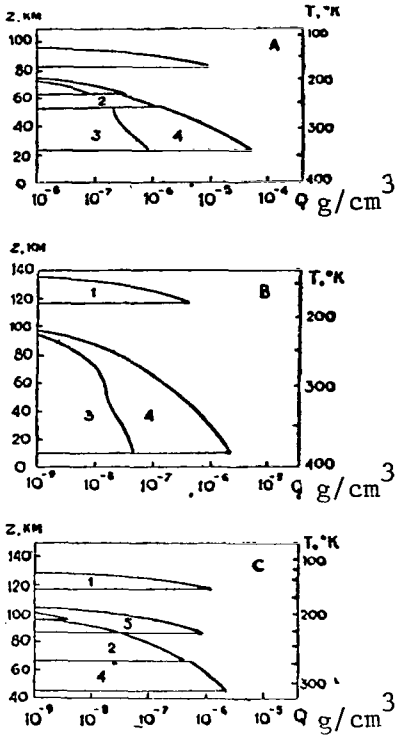


Figure 37. Layout of the possible structure of Jupiter's cloud layer (according to Lewis). The altitude distribution is shown for the bulk density of the cloud material (Q), which consists of solid NH_3 (1), H_2O ice (2), droplets of NH_3 (3), droplets of a solution of ammonia in water (4), and also of NH_4SH (5) for three models of the atmosphere's structure: A) 52.6% H_2 and 46.7% He; B) 92.9% H_2 and 5.8% He; and C) solar composition.

NATURE OF THE COLORATION OF THE CLOUD DETAILS (HYPOTHESES) /62

Author, year	Material	Coloration	Note
Wildt, 1939 [IV—138] Peek, 1958	Mixture of Na and other alkali metals in ammonia	From gray to reddish-bronze and blue for the phase transitions	T = 160-195°K. Na and other alkali metals have too great a chemical activity. The hypothesis is improbable.
Rice, 1956 [IV—109, 110]	Frozen free radicals		T = 78-148°K
	$(NH_2NH)_n$	Yellow	
	CH_2S	"	
	$(CH_3CH_2)_n$	"	
	$(NH)_n$	Blue	
	$(CH_2)_2N$	Bright Green	
	$(CH_2)_3CS$	Red	
	Acetylene polymer	"	

NATURE OF THE COLORATION OF THE CLOUD DETAILS (HYPOTHESES) (Continued)

Author, year	Material	Coloration	Note
Sagan et al., 1967 [IV—118]	Complicated organic compounds		They can be formed in electrical discharges at T = 1500°K inside the clouds or in the thermosphere.
Briggs, 1960 [IV—38]	Pyrene	Yellow	
	Coronene	"	
	Chrysene	Red and blue fluorescence	
	Asphalt	Yellow	
	Azulene	Blue	
	Azobenzene	Red	
	Acetylene		
	Ethylene		
	Ethane		
Woeller and Ponnamperuma, 1969 [IV—140]	Polymers which arise upon reactions of methane and ammonia under the influence of electrical discharges (acetylene, aeromatic hydrocarbons, hydrogen cyanide)	Brownish-yellow, pure yellow, and orange	Results of laboratory experiments.
Owen and Mason, 1969 [III—89a]	$(NH_4)_2S$	Yellow, strong absorption in the ultraviolet	Reaction of H_2S and NH_3.

OTHER HYPOTHESES

/63

Author, year	Cause of the coloration	Coloration and its variations	Note
Vsekhsvyatskiy, 1965, [II—20]	Volcanic ash	Dark belts in the cloud layer	The hypothesis concerning active volcanism seems improbable.

OTHER HYPOTHESES (Continued)

Author, year	Cause of the coloration	Coloration and its variations	Note
Münch and Younkin, 1964 [III—75]	Selective scattering by solid cloud particles	Coloration of the particles is neutral; chemical composition is uniform.	A practically monodispersed medium (particles of identical sizes in a given region is required.
Khodyachikh, 1967 [III—42]	Selective scattering in the supra-cloud haze	Coloration of the clouds (dark and bright) is neutral.	Differences in the coloration are too nonuniform to be explained by the effect of haze.
Papazyan, 1959 [IV—98]	Bombardment by solar protons	Variation in the coloration across the belts	Improbable hypothesis
Sharonov, 1950	Rayleigh scattering (the effect of opalescence)	Coloration of the clouds is neutral; the color depends on the albedo of the dark and bright belts.	Too large an optical thickness of a Rayleigh atmosphere is required.

The strong absorption band near λ 3 μ discovered in Jupiter's infrared spectrum (from observations with the Stratoscope-2 balloon telescope), which is characteristic of solid NH_3 according to laboratory investigations, is a unique experimental indication of the ammonia nature of the visible cloud layer.

However, the nature of the observed differences in coloration of the cloud details remains unclear up to this time.

The most probable explanation for the coloration of the cloud features is the presence of various chemical compounds which are possibly sensitive to temperature variation. The synthesis of such compounds can take place in the upper layers of the atmosphere by photochemical reactions or electrical discharges.

POSSIBLE STRUCTURE OF THE VISIBLE CLOUD LAYER

/64

Structure	Parameters	Author, year
Cloud layer with a level upper boundary	The boundary is lowered by 10 km towards the terminator.	Hess, 1953 [III—65]
Clouds of the cumulus type which rise above the main level of the cloud layer (convective)	The altitude of up to 20-30 km of the cumulus clouds experiences diurnal variations. $T \approx 230°K$ at the base.	Squires, 1957 [IV—127]
Clouds of the cirrus type (mechanical disturbance)		Opik, 1962 [IV—93]
Level layer with a diffuse fuzzy boundary		Kuiper, 1952 [I—20]
Minimal dimensions of the turbulent or convective elements of the cloud layer observed from the Earth	$d > 600$ km	
Difference in the altitudes of the cloud zones and belts, based on spectral observations	$\Delta Z \lesssim 3$-4 km	

SCATTERING COEFFICIENT

The value of the scattering coefficient was estimated from the nature of the distribution of molecular absorption across Jupiter's disk in the methane bands on the assumption of a two-layer model for the absorbing atmosphere, which takes into account the role of multiple scattering in the cloud layer.

ESTIMATES OF THE VOLUME SCATTERING COEFFICIENT

σ, cm^{-1}	Assumed scattering indicatrix	Author, year
$5 \cdot 10^{-6}$	Prolate	Moroz, 1967 [I—9]
10^{-6}	Spherical	Moroz, 1967 [I—9]
$(1\text{-}5) \cdot 10^{-7}$	Spherical	Teyfel', 1967-1970
$4 \cdot 10^{-6}\text{-}1 \cdot 10^{-5}$	Prolate	[III—34, 113a, I—11a]

The values of σ are found to be very low and most likely refer to the upper part of the ammonia clouds, which should bear a similarity in this zone to terrestrial fogs or haze, but with a large vertical extension. Further special investigations are necessary, since the results obtained are still not sufficiently determinate. /65

PROBABLE DIMENSIONS OF THE PARTICLES OF THE AEROSOL COMPONENT

Estimates of the sizes of the aerosol were carried out on the basis of data from photometric observations or were derived as being the most probable for an interpretation of the spectral observations of the intensity of molecular absorption bands, with account being taken of multiple scattering in the cloud layer.

ESTIMATES OF THE RADIUS OF THE PARTICLES

Radius, r, μ	Method	Author, year
1	Polarization in Jupiter's polar regions	Dollfus, 1955 [I—7]
0.075±0.010	Photometry of the disk	Aleksandrov, 1967 [II—6]
0.6	"	Khodyachikh, 1968 [III—42]
2	Interpretation of the spectral absorption bands	Moroz, 1967 [I—9]
1.15	"	Beckman, 1967 [III—49]
0.15-0.20	"	Avramchuk, 1968 [III—4]

DENSITY OF THE DISPERSED PHASE

We understand the density of the dispersed phase to mean the amount of condensed material per unit volume of the cloud. No special determinations of this quantity have been carried out, and the data are based on indirect ideas /66 and, of course, should be considered as preliminary.

The density of the dispersed phase (moisture) in terrestrial clouds exceeds 10^{-7} g/cm^3.

ρ(g/cm^3)	Original considerations	Author, year
1.3×10^{-9}	Based on Hess' spectral observations and calculations	Squires, 1957 [IV—127]
$\sim 10^{-7}$	Based on analogy with terrestrial clouds	Squires, 1957 [IV—127]
10^{-8}	Based on a scattering coefficient in the cloud layer for particle sizes of several microns	Moroz, 1967 [I—9]

OPTICAL THICKNESS OF THE CLOUD LAYER

Estimates of the optical thickness produced by scattering in the cloud layer are still only of a tentative nature, as are the estimates of the linear extent of the cloud layer in altitude.

ESTIMATES OF THE OPTICAL THICKNESS OF THE CLOUDS

τ_H	Author, year
10	Vsekhsvyatskiy, 1965 [II—20]
10-30	Moroz, 1967 [I—9]
15	Beckman, 1967 [III—49]

THE RED SPOT

The Great Red Spot on Jupiter is unique and has no analogies on any of the other giant planets. Investigations of this object, which has already been observed for at least 150 years and is evidently associated with the planet's interior, can give very important information about the structure and circulation of the deep layers of Jupiter's atmosphere. In contrast to the other details of the visible cloud surface, the Red Spot is a quasi-stationary feature and is located at practically one and the same latitude. A disturbance in the atmosphere, corresponding to the Spot's positions, constantly exists, although the Spot itself is not always visible (Figure 38).

GEOMETRICAL CHARACTERISTICS

Parameter	Value	Note
Length of the major axis	Up to 40,000 km	In 1964-1965 it was 27,000 km.
Length of the minor axis	13,000 km	In 1964-1965 it was 13,400 km.
Extent in longitude	$\sim 30°$	
Extent in latitude	$\sim 10°$	Sometimes the Spot appears narrower.

GEOMETRICAL CHARACTERISTICS (Continued)

Parameter	Value	Note
Longitude of the center	Variable	See Figure 39.
Latitude of the center	-22°.5±1°.5	
Area	Up to 3.7×10^8 km^2	

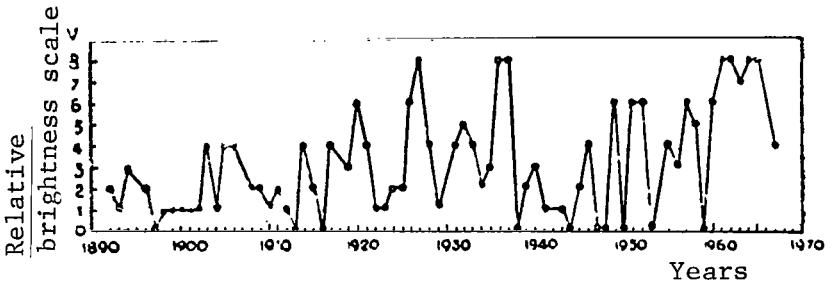


Figure 38. Variation in the visibility of the Red Spot from 1892 up to 1947 (according to Peek) and from 1948 up to 1967 (according to Solberg and Chapman).

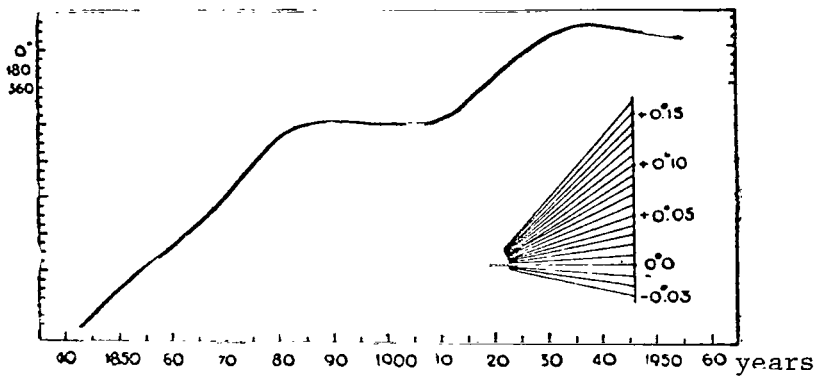


Figure 39. Variation of the Red Spot's longitude in System II (According to Löbering). The family of straight lines in the right-hand part of the graph indicates the rate of variation of the Spot's longitude per day.

The Red Spot appears elliptical only in the case of poor resolution. /67 Actually, the eastern and western edges are tapered and give it a spindle shape.

Period of rotation (Figure 40): Average — $9^h 55^m 37^s,6$, minimum — $9^h 55^m 32^s$, and maximum — $9^h 55^m 44^s$.

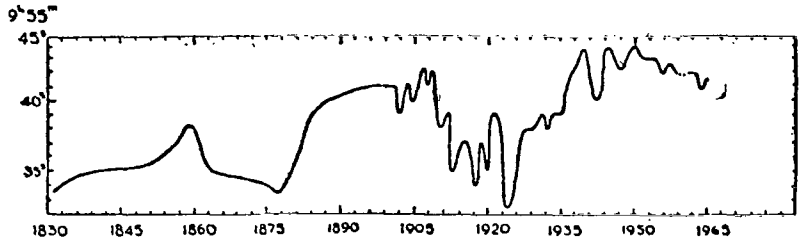


Figure 40. Oscillations of the Red Spot's period of rotation from 1830 up to 1965.

The flow velocity around the Red Spot by the surrounding atmospheric masses (V_c) is equal to approximately 2 m/sec.

Variation in the Spot's visibility. It is shown in Figure 38 how the visibility (contrast) of the Red Spot varied in the period from 1892 up to 1967 (in a nine-step scale: 0 denotes the Spot is invisible, 1 denotes that it is very weak, 4 denotes that it is easily noticeable, 6 that it is easily distinguished, and, 8 denotes that it is very dark). This graph is based on visual observations; therefore, the visibility estimates refer to the spectral region λλ 5000—6000 Å. The Spot, which usually has a reddish tint, appears darker and has more contrast in blue light /68

Color of the Spot from visual estimates. Various observers have estimated the Spot's color as intense pink, pale carrot-colored, brick-red, gray, and so on. Of course, these estimates are very subjective, just as are the estimates of the color of Jupiter's belts and zones, and they can be considered only as illustrative.

Optical characteristics. The optical characteristics of the Red Spot have practically not been investigated. Photographic observations show that

the Spot is practically invisible in red light, but it shows up very distinctly in blue and violet light.

CONTRAST OF THE SPOT WITH THE SOUTHERN TROPICAL ZONE ACCORDING TO PHOTOGRAPHIC MEASUREMENTS IN 1962 (TEYFEL', 1964 [II—31])

λ_{eff}, Å	I_{RS}/I_Z	Single-scattering albedo, ω_H	
		Spot	Zone
6250	0,92	0,96	0,97
5300	0,77	0,92	0,95
4200	0,68	0,88	0,93

The spectral variation of the Red Spot's relative brightness (with respect to the Southern tropical zone) is shown in Figure 41 on the basis of observations in 1964 (Teyfel', 1967 [III—30]).

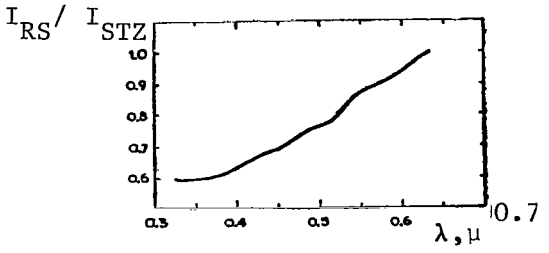


Figure 41. Spectral reflectivity of the Red Spot with respect to the S. tropical zone (according to Teyfel').

As these photometric observations show, the Red Spot's contrast with the surrounding surface decreases as it approaches the limb of Jupiter's disk (Figure 42).

The physical nature of the Red Spot still remains puzzling. Of all the hypotheses which have been advanced, only R. Hide's hypothesis connects in the best way the observed dynamical properties of the Red Spot with the hydrodynamics of Jupiter's atmosphere. The weakest point in this hypothesis is its requirement of an exchange of angular momentum between Jupiter's mantle /69 and core in order to explain the nonuniformity in the Red Spot's rotation.

The rotational motion of atmospheric masses around the Red Spot in the counterclockwise direction with a period of 9-12 days, which was discovered by B. Smith and E. Reese (1968 [II—93a]), agrees with this hypothesis. Concerning the visible phenomena of the Red Spot, the data of optical investigations (Teyfel', 1964-1968 [II—31, III—30, 33, 33a]) confirm the gaseous-aerosol (cloud) nature of the object observed at the surface of Jupiter's cloud layer. /70

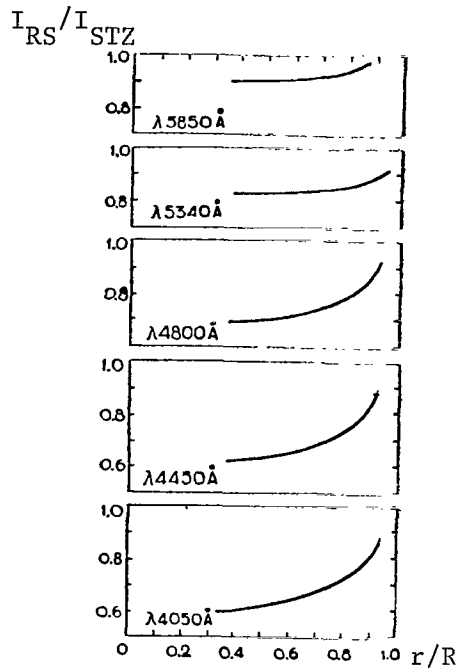


Figure 42. Variation in the Red Spot's contrast (intensity with respect to the S. tropical zone) at various wavelengths on the basis of spectral measurements (according to Teyfel') as the limb of Jupiter's disk is approached.

OPTICAL PARAMETERS OF THE SPOT ON THE BASIS OF 1964 SPECTRAL OBSERVATIONS (TEYFEL', 1967 [III—30]) FOR A SPHERICAL SCATTERING INDICATRIX

λ, Å	Reflectivity at the central meridian	Single-scattering Albedo, ω_H	
		Spot	Zone
5850	0,90	0,99	0,99
5340	0,83	0,98	0,99
4800	0,69	0,95	0,98
4450	0,61	0,92	0,97
4050	0,59	0,86	0,95

SOME CHARACTERISTICS OF THE RED SPOT ON THE BASIS OF SPECTRAL AND RADIOMETRIC OBSERVATIONS

Parameter	Value	Method of Determination	Author, year
Spot's temperature difference with respect to the surrounding surface	$\Delta T = -1°,5 - -2°$	Radiometry at 8—14 μ	Wildey, Murray, and Westphal, 1965 [III—119]
"	$\lvert\Delta T\rvert \leqslant 2°$	Intensity of NH_3 absorption bands	Teyfel', 1967-1969 [III—33, 33a]
Difference in altitude of the spot's upper boundary with respect to the surrounding surface	$\lvert\Delta Z\rvert \leqslant 2,5 - -3$ км	Intensity of the CH_4 6190 Å band	"
"	$\Delta Z \simeq +6$ км	Intensity of the CH_4 8900 Å band	Owen and Mason, 1969 [III—89a]
Relative spectral photometric gradient at λ 4200-6200 Å (with respect to the Southern tropical zone)	$G = +0,56$	Continuous spectrum	Teyfel', 1967-1969 [III—30, 33a]
Color excess	$\Delta(B-V) = +0^m,28$	"	"

HYPOTHESES ON THE PHYSICAL NATURE OF THE RED SPOT

/71

Hypothesis	Inadequacies of the hypothesis	Author, year
Volcanic eruption	Contradicts contemporary ideas as to the internal structure and temperature of Jupiter	Many authors (1885-1920)

HYPOTHESES ON THE PHYSICAL NATURE OF THE RED SPOT (Continued)

Hypothesis	Inadequacies of the hypothesis	Author, year
"Island" of solid material floating in an ocean of a highly compressed gas	Unaccountable latitude stability; a floating object on a rotating planet should be shifted towards the equator. Too great a gas density is required at small depths.	Wildt, 1939 [IV—138]
Floating island consisting of material in two phases, which possess, due to phase transitions, the ability to vary their immersion depth.	The author acknowledged the unsoundness of this hypothesis in 1963.	Peek, 1958 [I—24]
A stable hydrodynamic disturbance (Taylor column) in the atmosphere above an irregularity of the solid surface (a bulge or a depression). The height (or depth) of the irregularity should be of the order of 1 km in all (Figure 43).	The hydrodynamic and physical conditions in the lower atmosphere and on Jupiter's surface are unknown, as are also the nature of the rotation of the core and mantle. This hypothesis is reinforced by laboratory experiments.	Hide, 1961 [IV—59]
A region in the atmosphere where phase separation occurs for a two- or three-component mixture of gases under the condition that both phases have an identical density but a different chemical composition.	This hypothesis does not explain why such phase transformations should take place in a restricted region of the atmosphere.	DeMarcus and Wildt, 1966 [IV—83]

MODELS OF THE LOWER ATMOSPHERE'S STRUCTURE

Hydrogen Models of DeMarcus (1953-1957)

W. DeMarcus [IV—77—81] calculated the depth distribution of the density in Jupiter's lower atmosphere (right down to its solid surface), assuming this region of the atmosphere to be isothermal and to consist of pure molecular hydrogen. He showed that the density of strongly-compressed hydrogen in the deep layers can become almost constant with depth, regardless of the increase /72 in the pressure. This situation recalls the terrestrial oceans. DeMarcus introduces the term "hydrogen ocean" to characterize the near-surface zone of the lower atmosphere. At T = 150°K the depth of such an "ocean" is equal to approximately 240 km, and the pressure at the solid surface is about 27,000 atm (Figure 44).

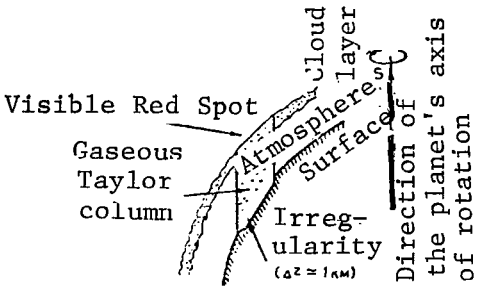


Figure 43. Scheme for the Red Spot's formation according to Hide's hypothesis.

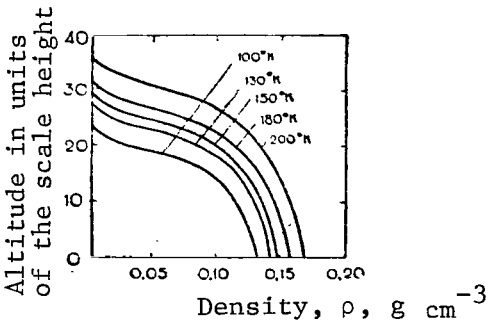


Figure 44. Variation in the density of Jupiter's lower atmosphere with depth for several isothermal models (according to DeMarcus).

Since Jupiter's atmosphere does not consist of pure hydrogen and can scarcely be close to isothermal with moderate temperatures in the lower layers, DeMarcus' model is evidently far from reality, although the possibility that a strongly compressed gas (an "ocean") exists is not excluded.

Gallet's Model (1962)

R. Gallet's model, which is unfortunately described only in general outline in a review [I—31], is still the only model for Jupiter's lower atmosphere which is calculated with account taken of the chemical composition and moist adiabatic processes which take place in the presence of condensed components (NH_3 and H_2O).

The details of this model involve the fact that high pressures and densities are attained at comparatively low temperatures, in contrast to what a dry adiabat gives. The altitude on the graphs representing the results of Gallet's calculations is figured downward in the atmosphere from the surface of the cloud layer (Figures 45, 46).

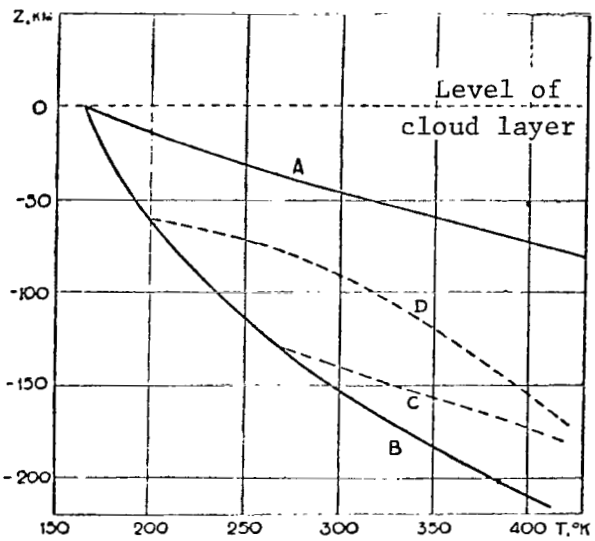


Figure 45. Variation in the temperature with depth in Jupiter's lower atmosphere (according to Gallet). A) dry adiabat; B) wet adiabat for 2.22% NH_3; C) the same for 1.53% NH_3; and D) the same for 1.07% NH_3.

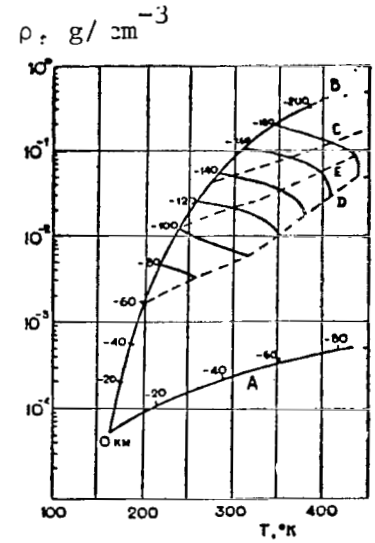


Figure 46. Relation between density and temperature in Jupiter's lower atmosphere (according to Gallet). A) Dry adiabat; B, C, D, and E) Wet adiabats for a 2.22, 1.53, 1.07, and 1.36% NH_3 content, respectively. The numbers next to curves A and B are depths (km).

Initial parameters of the model. The temperature on the surface of the cloud layer is equal to 165°K, and the density is $\rho_0 = 5 \cdot 10^{-5}$ g/cm^3.

PHASE STATE OF THE MATERIAL IN THE DEEP LAYERS

Recently, W. Street (1969 [IV—127b]) discussed probable phase diagrams for a mixture of hydrogen and helium at high pressures. As the data presented show, hydrogen can change into the solid phase at lower pressures than that which is necessary for the solidification of helium, i.e., phase separation of these gases is possible in the lower layers of Jupiter's atmosphere: solid hydrogen will float on the surface of a layer of liquid helium (if the atmosphere is isothermal in this zone).

Whether or not this situation corresponds to the actual situation in Jupiter's lower atmosphere is, of course, not clear, since it is not known whether or not the lower atmosphere is isothermal or adiabatic. /74

PRESSURE OF THE TRANSITION TO THE SOLID PHASE

Temperature, °K	Pressure, 1000 atm	
	He	H_2
100	22.5	8.3
300	124	57
500	275	138
1000	810	460

THE TOTAL THICKNESS OF THE ATMOSPHERE

We understand by the total, or entire, thickness of the atmosphere to be the distance from the "solid" surface of Jupiter to the upper boundary of the cloud layer ($R_0 - R_s$). Estimates of this quantity are still very approximate, since they are based on certain assumptions as to the structure of the planet's lower atmosphere. The most probable value is about 800 km, although

the possibility that the atmosphere does not have a sharply-expressed lower boundary at all is not excluded.

$h = R_0 - R_T$, km	Basis for the estimate	Author, year
800-1000	Model of an isothermal hydrogen atmosphere	DeMarcus, 1953 [IV—77]
2800	Hydrodynamic calculations for the Red Spot	Hide, 1963 [IV—60]
4250	Adiabatic model of the lower atmosphere and calculations of Jupiter's internal structure	Peebles, 1964 [IV—99]
500	Adiabatic model	Wildt, 1934 [I—4]

INTERNAL THERMAL ENERGY

The fact that Jupiter's radiometric temperature appears to be significantly higher than its radiative equilibrium temperature indicates the existence of excess thermal emission. The output of Jupiter's own thermal emission is found /75 to be on the order of 10^4 ergs/cm^2·sec.

Radiation temperature T, °K	Radiometric T, °K	$E_{exc}/E_{\odot}$	Author, year
102	130	2.62±0.4	Öpik, 1962 [IV—93]
105±3	128	2.2	Taylor, 1965 [III—111]
105±3	134±4	2.7±0.6	Aumann et al., 1969 [III—47b]

According to L. Trafton's calculations (1964 [IV—129]), the excess of Jupiter's thermal emission can be explained at least in part by the greenhouse effect produced because of the absorption of infrared radiation by ammonia and

in particular by molecular hydrogen (pressure-induced absorption).

The most probable mechanism for internal heating is considered to be the gravitational contraction of Jupiter; as a result of it, a fair amount of energy is accumulated in its core. According to D. Taylor's calculations (1965 [III—111]), the constant outward flow of this energy agrees well with the observed temperature of this planet.

CIRCULATION AND ACTIVE PROCESSES IN THE ATMOSPHERE

Regardless of the large number of measurements of the rotational velocity of various cloud zones and details, the regularities and the circulation mechanism of Jupiter's atmosphere have yet been poorly studied. Thus up to the present time it is not clear what serves as the main source of the convective energy; the source may be internal heating of the planet or the greenhouse effect in the atmosphere. Also unclear are what are the initial parameters (temperature at the solid surface, thickness of the atmosphere). The few provisional models for the circulation worked out are far from adequate and are not discussed here.

The rapid variations which occur in Jupiter's cloud layer reflect active processes in its atmosphere, the reason for which is also still unclear. To solve the problem of what is the main energy source causing Jupiter's atmospheric activity (internal heat, solar radiation, or the tidal effects of the satellites), lengthy and continuous observations of this planet are necessary.

Below are presented some observational data on the active processes and the circulation as a supplement to the characteristics of the rotational velocity of Jupiter's various zones mentioned earlier.

SPINRAD EFFECT

/76

In 1962, H. Spinrad discovered that lines of the 6450 Å NH_3 band on a spectrogram of Jupiter's equator have a slope αA which is not 0.50 of the

slope of the Fraunhofer lines, as should be the case for lines which are formed in the planet's atmosphere, but instead is 0.23-0.34. In order to explain this effect, he assumed that the motion of gaseous masses in the outer atmosphere occurs in a direction opposite to the direction of the planet's rotation, with a relative velocity $V \leq 6$ km/sec (from west to east). All the results of measurements of the slope of the NH_3 lines in Jupiter's spectrum in various years are presented in the table below.

SLOPE OF LINES IN THE NH_3 6450 Å BAND

Author	Year of the observations	Zone of the disk	α_A
Spinrad [III—101]	1934	Equator	0.23±0.06
"	1954	$\phi = +45°$	0.42±0.05
"	1961	Equator	0.34±0.06
Sargent and Catchpole [III—95]	1962	Equator and $\phi = +60°$	0.50
Fehrenbach and Guerin [III—58]	1963	Equator	0.492
Nishida and Jugaku [III—80]	1963	"	0.412±0.024
Giver [III—61]	1963	"	0.485
Münch	1963	"	0.485
Spinrad and Giver [III—104]	1964	"	0.50
"	1965	"	0.50

Thus the "Spinrad effect" is a variable phenomenon, and the observations of recent years do not detect it. T. Owen and D. Staelin (1963 [III—91]) expressed an assumption as to a possible analogy of this effect with the terrestrial stratospheric zonal winds, which change their direction with a periodicity of 26 months. The observations of M. Nishida and J. Jugaku [III—80] in the fall of 1963 would appear to agree with such an assumption.

But this effect still remains doubtful, especially as the hypothesis of zonal winds in Jupiter's outer atmosphere encounters certain difficulties connected with the optics of the phenomenon.

AVERAGE LIFETIME OF THE CLOUD DETAILS

According to R. Falwell (1963 [II—59]), who investigated various cloud features on Jupiter in 1961, their average lifetime $\bar{t}$ has the values given in the following table.

Region	$\bar{t}$, days	Number of features
Equator	11.6	102
Southern temperate belt	12.9	28
In the region of the Red Spot and inside the Spot	10.8	46

/77

PERIODICITY IN THE LATITUDE AND WIDTH VARIATIONS OF THE CLOUD BELTS

The latitudes and width of dark belts on Jupiter's disk undergo rather strong variations in the course of time. Attempts to establish the periodic nature of such variations and to connect them with the solar activity have not given positive results. One can say only that there is some periodicity to the process of the variations in position and dimensions of the belts. The values of such cycles according to the estimates of various authors are not found to be the same.

Belt	Periodicity of the latitude variations, years	Periodicity of the width variations, years	Author, year
N. Equatorial		4.5	Freitas Mourao, 1963 [II—97]

Belt	Periodicity of the latitude variations, years	Periodicity of the width variations, years	Author, year
N. Equatorial	11.4		Schoenberg and Heintz, 1955 [II—99]
"	11.4		"
S. temperate	12-15		Focas, 1963 [II—61]
"	14-16		"
S. equatorial (S. component)	4-6		"
S. equatorial (N. component)	12-16		"
N. equatorial (S. component)	12-16		"
N. equatorial (N. component)	3-6		"
N. temperate	10-14		"
N. equatorial		3.5-4.1	Bronshten, Sedyakina, and Strel'tsova, 1967 [II—16a]
S. equatorial		3.5-4.1	"

Long-term oscillations in the circulation of Jupiter's atmosphere (variations of the rotational velocity) during the period from 1900 until 1939 were investigated by B. M. Rubashev (1953) for the appearance of a correlation with solar activity. Smoothed curves of the variation in the rotational periods of various cloud belts (atmospheric currents) on Jupiter and the numbers of sunspots are shown in Figure 47. These graphs are constructed on the basis of /80 a sliding average over ten-year intervals.

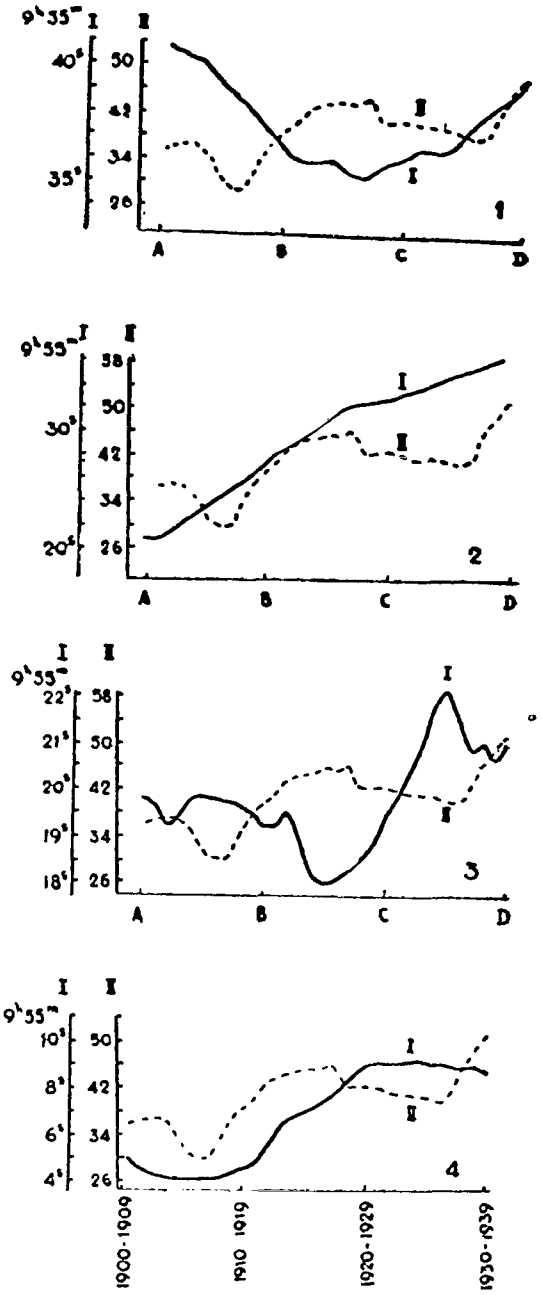
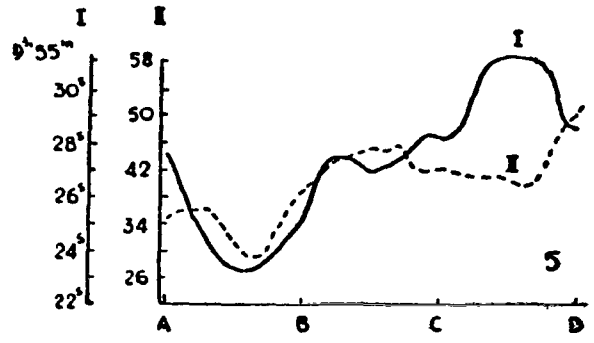
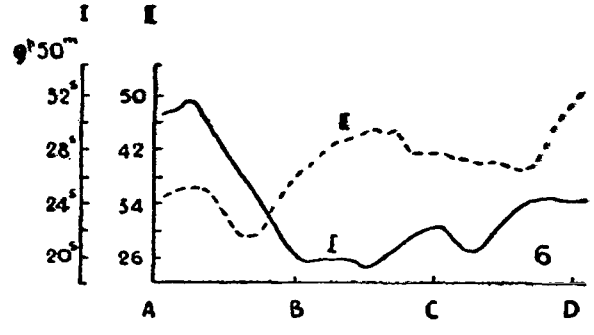
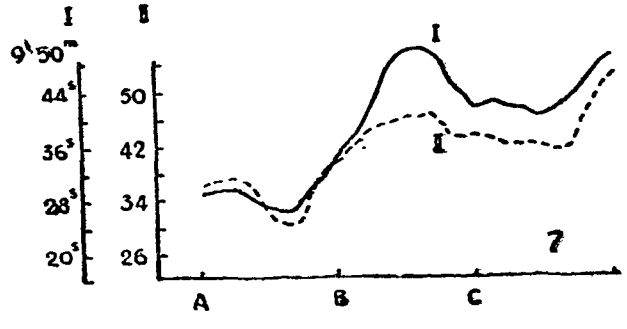


Figure 47. Smoothed curves of the variation in the rotational periods of various cloud zones of Jupiter (I) and the numbers of sunspots (II) on the basis of a sliding average over ten-year intervals (according to Rubashev).

(Figure 47 and caption continued on following page)







1) Red Spot (ϕ = -22°); 2) S. tropical disturbance (ϕ = -23°) 3) S. temperate current (ϕ = -27° - -37°); 4) S. arctic current (ϕ = -37° - - 55°); 5) N. tropical current (ϕ = +10° - +20°); 6) N. equatorial current (ϕ = 0° - +10°); and 7) s. equatorial current (ϕ = 0° - -16°).

Shapiro (1953 [II—101])

The relative intensities (B — yearly averages for the entire disk) of 18 latitude belts of Jupiter have been measured on Lowell Observatory photographs for the period 1926-1950 taken in blue and yellow light, and their correlation with the Wolf numbers (W) has been investigated.

CORRELATION COEFFICIENTS

Correlation parameters	r	Number of estimates
$B_{blue} - W_{av.\ yr.}$	0.811	17
$B_{blue} - W_{av.\ mon.}$	0.798	17
$B_{yel} - W_{av.\ yr.}$	0.637	13
$B_{yel} - W_{av.\ mon.}$	0.623	13

At high latitudes the individual correlation coefficients in blue light for $B - W_{av.\ yr.}$ are found to be higher than near the equator. One should note that the high values of the correlation coefficients were most probably obtained as a result of an accidental agreement of the variation in the intensity of the belts on Jupiter's disk with the variation in solar activity just at this period. As will be seen below, such a correlation has not been observed.

Focas and Banos (1964 [II—63])

The variation in the relative amount of dark material in the region of latitudes $\phi = -30°$ to $+30°$ has been photometrically investigated in yellow light during the period from 1952 up to 1963. The so-called activity coefficient R, an increase of which corresponds to an increase in the amount of dark material, was determined from photographs in yellow light and had the following values:

Year	R	Year	R
1952	0,251	1959	0,179
1955	0,183	1960	0,138
1956	0,176	1961	0,149
1957	0,159	1962	0,233
1958	0,189	1963	0,209

Focas (1966 [II—62])

/81

The variations in the cited activity coefficient (R) during the period from 1904 up to 1963 have been investigated photometrically with the help of Lowell Observatory photographs. The variations in R for the entire disk and separately for the northern and southern hemispheres of Jupiter and the variation of the Wolf numbers (W) are shown in Figure 48. In the southern hemisphere, two secondary maxima are observed between the primary maxima, which alternate every 17-20 years, while in the northern hemisphere the difference between successive maxima is noticed with difficulty, and the atmospheric activity comes closer to an 11-year cycle.

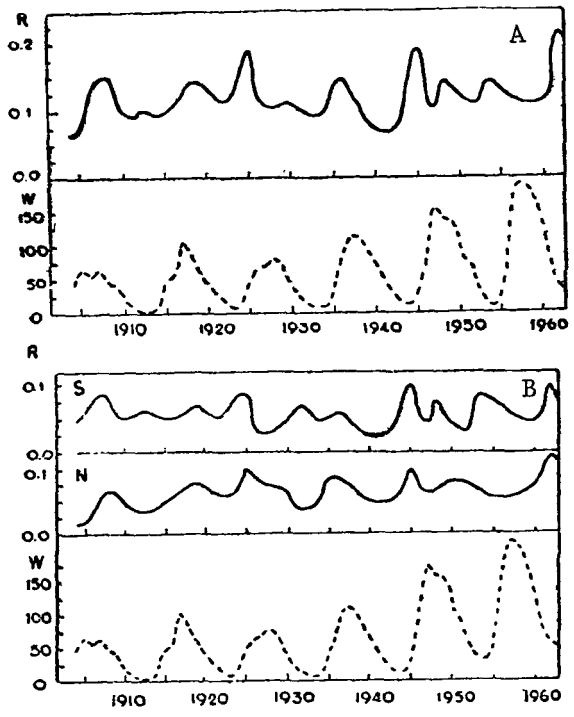


Figure 48. A) variations in Jupiter's atmospheric activity (the activity coefficient R for the planet's entire disk) and solar activity (Wolf numbers W) from 1905 up to 1962 (according to Focas); B) the same but separately for the southern (S) and the northern (N) hemispheres of Jupiter.

There is no distinct correlation of the values of R with solar activity. The active processes proceed differently in the northern and southern hemispheres of Jupiter.

Aksehov, Grigor'eva, Priboyeva, Romanenko, and Teyfel' (1967 [II—1, 2, 3]) /82

Measurements of the photometric factor or the activity coefficient of Jupiter during 75 nights of observations in 1964-1965 revealed short-term oscillations in the value of R, which were most clearly expressed in light of long wavelength in the planet's northern hemisphere. R is a maximum at short wavelengths:

λ_{eff}, nm	Limits of the variations of R
605	0,115—0,215
585	0,118—0,246
532	0,109—0,250
441	0,182—0,328
405	0,203—0,419

Sorokina (1969 [II—29a])

The activity factor R was determined in 1965-1966 during 34 nights of observations. Again a difference in the degree of activity of the atmosphere in the northern and southern hemispheres was detected (the northern was more active):

λ_{eff}, nm	R_N	R_S	R (for the entire disk)
590	0,088—0,283	0,062—0,194	0,091—0,238
532	0,119—0,257	0,085—0,199	0,102—0,228
423	0,117—0,306	0,065—0,184	0,102—0,240
405	0,140—0,313	0,061—0,214	0,111—0,247

A clearly-expressed correlation between R_S and R_N was present. An increase was noted in 1966-1967 in the activity factor in the southern hemisphere.

An autocorrelation analysis revealed the existence of short-period variations of Jupiter's activity factor with a period of 20 ± 4 days. In the northern hemisphere these oscillations are superimposed on a longer period of 60 days. An autocorrelation analysis applied to the data of Focas (1966 [II—62]) led to the discovery of a period of nine years for the variations in the yearly values of R for both of the planet's hemispheres.

No clear connection of the short-term variations of Jupiter's activity factor with solar activity (Wolf numbers) was detected. The correlation coefficient for orange light is equal to +0.07 (1964-1965), +0.26 (1965-1966) and +0.40 (1966-1967). This weak correlation was possibly connected with the low level of the solar activity.

STRUCTURE OF THE UPPER ATMOSPHERE /83

There are no observational data on the upper atmosphere (starting approximately from an altitude of 80 km above the level of the tropopause).

D. Hunten (1969 [IV—69a]) and R. Henry and M. McElroy (1969 [IV—55a]) have carried out theoretical calculations of the distribution of hydrogen and helium, with account taken of diffusive separation and photodissociation of the hydrogen molecules (Figure 49). Calculations of the concentration of atomic hydrogen and electrons in the upper atmosphere were made earlier by S. Gross and S. Rasool (1969 [IV—54]). Since the assumed initial models of the atmosphere were rather tentative in themselves, it is completely understandable /84 that the discrepancies in the results of various authors reach several orders of magnitude.

W. McGovern (1968 [IV—83a]) made an attempt to estimate theoretically the temperature of Jupiter's exosphere above the mesopause level (for which he assumed an altitude of 140 km above the tropopause level and a density of 5×10^{13} cm^{-3} by number of molecules). It was also assumed that the main agent which maintains the radiative cooling of the exosphere is ethane (C_2H_6), which

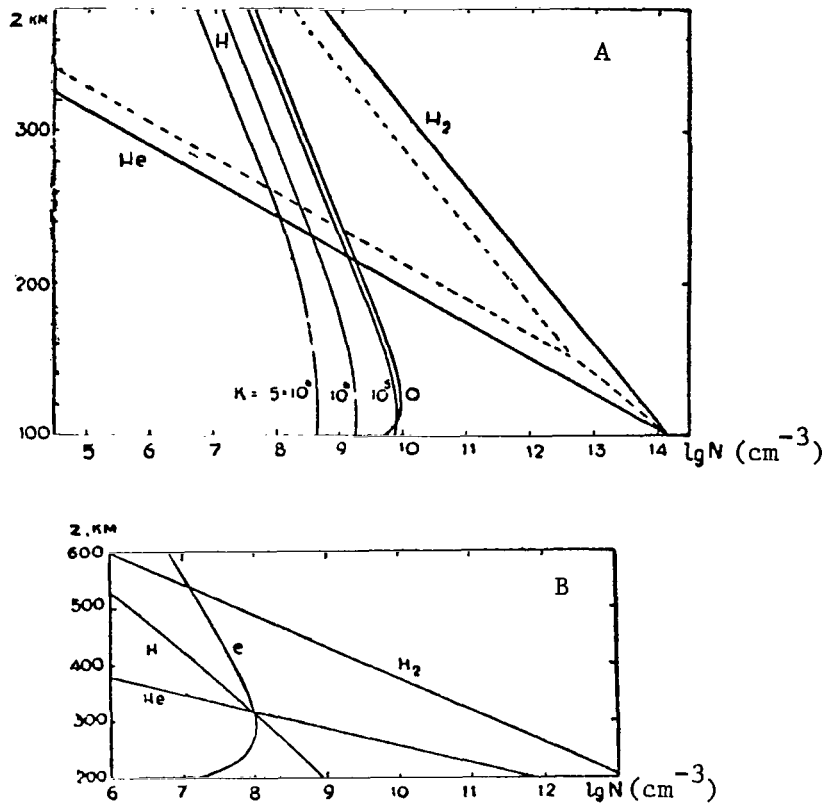


Figure 49. A) distribution with altitude in Jupiter's upper atmosphere of the hydrogen (molecular and atomic) and helium concentrations; K is the diffusion coefficient and z is the altitude above the tropopause (according to Hunten); B) distribution of the concentrations of H_2, H, He, and free electrons with altitude in Jupiter's upper atmosphere (according to Henry and McElroy).

forms as a result of photochemical reactions. The fraction of the solar ultraviolet radiation which is absorbed in the exosphere and converted into heat was assumed to be equal to 0.25 and 0.50. The corresponding values of the exosphere's temperatures are given in the following table.

Composition of the atmosphere near the mesopause, %			Temperature of the exosphere, °K	
H_2	He	C_2H_6	At minimum solar activity	At maximum solar activity
2,30	97,68	0,02	136—144	154—182
62,62	37,36	0,02	140—154	173—220
62,30	37,20	0,50	137—146	158—214
78,18	21,80	0,02	141—156	174—228

PHOTOCHEMICAL PROCESSES IN THE UPPER ATMOSPHERE

The short-wavelength ultraviolet radiation of the Sun $\lambda < 2000$ Å causes photodissociation of the molecules of hydrogen, methane, and ammonia in Jupiter's upper atmosphere. The products obtained can again enter into reactions among themselves, which leads to the formation and subsequent photolysis of new chemical compounds or to the regeneration of the original molecules. The photochemistry of Jupiter's atmosphere is a little-studied area. Theoretical calculations carried out by R. Wildt (1937 [IV—137]), R. Cadle (1962 [IV—41]), S. Gross and S. Rasool (1964 [IV—54]), J. McNesby (1969 [IV—83b]), and D. Strobel (1969 [IV—127c]) are based on the data of laboratory investigations, which are still far from complete. The rates at which these different reactions proceed are not yet known very exactly, particularly under conditions corresponding to the upper layers of the atmospheres of the giant planets. Below some of the possible reactions in Jupiter's upper atmosphere are enumerated.

REACTIONS OF HYDROGEN AND HELIUM (ACCORDING TO GROSS AND RASOOL)

Type of reaction	Reaction	Reaction rate, $cm^3 \cdot sec^{-1}$	Note
Photoionization	$H_2+h\nu \rightarrow H_2^+ + e$	$\sigma(H_2)$	$\lambda \leqslant 804$ Å
	$H + h\nu \rightarrow H^+ + e$	$\sigma(H)$	$\lambda \leqslant 912$ Å
	$He+h\nu \rightarrow He^+ + e$	$\sigma(He)$	$\lambda \leqslant 504$ Å
Charge transfer and ionic-molecular reactions	$He^+ + H_2 \rightarrow He + H_2^+$	$\alpha = 10^{-13}$	Estimate
	$He^+ + H_2 \rightarrow HeH^+ + H$	$\alpha = 10^{-12}$	Upper limit
	$H_2^+ + H_2 \rightarrow H_3^+ + H$	$\alpha = 5 \cdot 10^{-10}$	—
	$H_2^+ + H \rightarrow H^+ + H_2$	$\alpha = 10^{-10}$	Not measured
	$H_2^+ + He \rightarrow HeH^+ + H$	$\alpha = 10^{-10}$	—

REACTIONS OF HYDROGEN AND HELIUM (ACCORDING TO GROSS AND RASOOL)
(Continued)

Type of reaction	Reaction	Reaction rate, $cm^3 \cdot sec^{-1}$	Note
Recombination	$H_2^+ + e \rightarrow H' + H''$	$\alpha = 10^{-8}$	Upper limit
	$HeH^+ + e \rightarrow He + H$	$\alpha = 10^{-8}$	Estimate
	$He^+ + e \rightarrow He$	$\alpha = 10^{-12}$	Theoretical calculation
	$H_3^+ + e \rightarrow H_2 + H$	$\alpha = 10^{-8}$	Estimate
	$H^+ + e \rightarrow H$	$\alpha = 10^{-12}$	Theoretical calculation
	$H + H + M \rightarrow H_2 + M$	$\alpha = 10^{-22}$	M can stand for H_2 or He.
	$H + e \rightarrow H^- + h\nu$	$\alpha = 10^{-16}$	Very Small

REACTIONS OF METHANE AND AMMONIA (ACCORDING TO CADLE)

Reaction	Reaction rate, $cm^6 \cdot mol^{-2} \cdot sec^{-1}$	Note
1	2	3
$CH_4 + h\nu \rightarrow H + CH_3$		$\lambda \leqslant 1600$ Å
$CH_3 + CH_3 + M \rightarrow C_2H_6 + M$	$7.8 \cdot 10^{-30}$	
$H + H + M \rightarrow H_2 + M$	$(2.5 \pm 2) \cdot 10^{-32}$	
$CH_3 + H + M \rightarrow CH_4 + M$	10^{-31}	
$C_2H_6 + h\nu \rightarrow 2CH_3$		$\lambda \leqslant 1500$ Å
$CH_3 + H_2 \rightarrow CH_4 + H$		Require large activation energies.
$CH_3 + C_2H_2 \rightarrow CH_4 + C_2H_5$		
$NH_3 + h\nu \rightarrow NH_2 + H$		$\lambda = 1000 - 2200$ A
$NH_2 + H + M \rightarrow NH_3 + M$	10^{-31}	
$NH_2 + CH_3 + M \rightarrow CH_3NH_2 + M$	10^{-32}	
$NH_2 + NH_2 + M \rightarrow (NH_2)_2 + M$	10^{-1}	
$CH_3NH_2 + h\nu \rightarrow CH_3 + NH_2$		$\lambda \leqslant 2000$ Å
$(NH_2)_2 + h\nu \rightarrow 2NH_2$		$\lambda \leqslant 2700$ Å
$CH_3 + C_2H_6 \rightarrow CH_4 + C_2H_5$		These reactions can proceed only at relatively high temperatures.
$NH_2 + C_2H_6 \rightarrow NH_3 + C_2H_5$		

SEARCHES FOR EMISSION IN THE UPPER ATMOSPHERE /86

In 1960 J. Jelley and A. Petford expressed an assumption concerning the possibility of the appearance on Jupiter, particularly during periods of strong outbursts of radio emission, of polar aurorae, which can be observed as an emission component in the Hα line. These authors carried out observations over a number of years of individual regions of Jupiter's disk in the vicinity of

the Hα line [III—66, 67], but they did not obtain a positive result. Similar investigations were carried out by other authors in the neighborhoods of both the Hα line and the Hβ, He I 6678 and 5876 Å lines. With the exception of a single doubtful case, no success was achieved in detecting emission. This result does not indicate that there cannot be polar aurorae in Jupiter's atmosphere, but it permits one to assert that their brightness does not exceed a value of 3 kilorayleighs.

Rotational Period of the Sources of Radio Emission

The periodicity of outbursts of Jupiter's radio emission in the decametric region is similar to the rotational period in temperate latitudes (T_{II}), but it is not equal to this period. Therefore, a special system for counting longitudes has been adopted for the radio sources on the planet with a rotational period T_{III}.

ROTATIONAL PERIOD T_{III} BASED ON THE OBSERVATIONS OF RADIO EMISSION

Region	T_{III}	Author, year
1	2	3
Decametric	$9^h55^m34^s \pm 7^s$	Barrow and Carr, 1958 [IV—30]
	$9^h55^m29^s,35$	Carr and Smith, 1961 [V—55]
Decimetric	$9^h55^m29^s,70 \pm 0^s,04$	Bash and Drake, 1964 [V—35]
	$9^h55^m29^s,55$	Smith and Lebo, 1965 [V—199]
Decametric	$9^h55^m29^s,70 \pm 0^s,5$	Duncan, 1967 [V—97]
	$9^h55^m29^s,37 \pm 0^s,16$	Douglas, 1961 [V—73]
Average	$9^h55^m29^s,70 \pm 0^s,5$	

RADIO EMISSION IN THE CENTIMETER REGION /87

The brightness temperature of Jupiter's radio emission in the 3 cm $\lambda <$ 10 cm region is significantly higher than the infrared temperature, which it is not possible to explain by a thermal mechanism for the emission. The nature of

the non-thermal mechanism of radio emission is still quite unclear. Possibly it is synchrotron emission of relativistic electrons in the inner zone of the radiation belt (1.3 ± 0.2) R_J, as is the decimetric radio emission.

CHARACTERISTICS OF THE RADIO EMISSION IN THE 6-10 cm REGION

λ, cm	T_B, °K	Flux density (10^{-26} watt/ m^2·hertz)	Polarization of the radiation, %	Author, year
6	300	10.0		Roberts and Komesaroff, 1965 [V—173]
6	396±6	10.8±0.6		Dickel, 1966 [V—72]
6.5	324±30	11.0±1.0		Pariyskiy, Yu. N., 1963 [V—12]
9.4	658±39	9.0±0.5	20±8 Linear	Rose et al., 1962 [V—177]

DECIMETRIC RADIO EMISSION

Jupiter's radio emission in the decimetric region is characterized by a rapid increase in the brightness temperature with wavelength (Figure 50). In contrast to the decametric radiation, it is quiet, but its connection with non-thermal processes in the region of the radiation belts which surround the planet is completely evident.

The polarization of the decimetric emission is linear and amounts to about 20-25% according to the data of the majority of investigators. /89

On the basis of the fact that the dimensions of the emitting region in the decimetric region exceed by far the dimensions of the planet itself

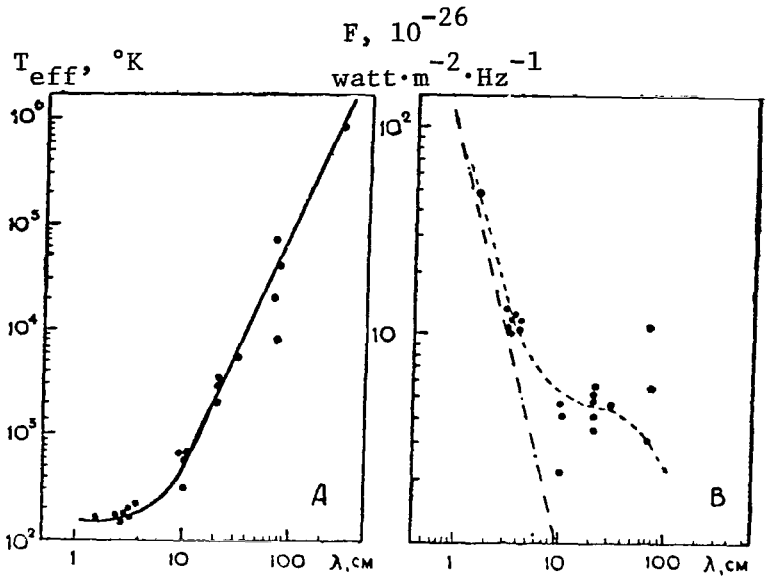


Figure 50. Spectrum of Jupiter's radio emission (according to Zheleznyakov): A) effective temperature; B) emission flux.

CHARACTERISTICS OF JUPITER'S DECIMETRIC RADIO EMISSION

/88

λ, cm	μ, MHz	T_B, °K	Emission flux density (10^{-26} watt/m^2·Hz)	Author, year
1	2	3	4	5
10	3000	Varied from May to June 1959 from 2860 ± 380°K to 2050 ± 430°K.		McClain, 1959 [V—142]
10.0	3000	690	7.8	Bash and Drake, 1961-1963 [V—35]
10.3	2900	650±250		Field, 1960 [V—105]
10.3	2900	640±85	7.2±0.7	Sloanaker, 1964 [V—191]
10.5	2840	800±100		Morris et al., 1962 [V—153]
11.3	2650	810	7.3	Roberts and Komesaroff, 1965 [V—173]
13		1010±100		Boischot, 1961 [V—45]

CHARACTERISTICS OF JUPITER'S DECIMETRIC RADIO EMISSION (Continued)

λ, cm	μ, MHz	T_B, °K	Emission flux density (10^{-26} watt/m^2·Hz)	Author, year
1	2	3	4	5
20.8	1440	2900±400	8.0±1.5	Miller and Gary, 1962 [V—151]
21	1435	496±450		McClain, 1959 [V—141]
21	1435	2950±375	4.1	Boishot, 1961 [V—44]
21	1435	2590±200	5.5	Miller and Griffin, 1967
			3.4	[V—152]
21	1435		6.4±0.6	Conway and Kronberg, 1967 [V—64]
21.2	1430	2500±500	6.7±1.3	McClain et al., 1958 [V—142]
21.3	1420	6200	16.0	Epstein, 1959 [V—104]
21.3	1420	2800	7.3	Roberts and Komesaroff, 1965 [V—173]
21.4	1405	3500±1700		Field, 1960 [V—106]
22	1360	3000	6.0	Drake and Hvatum, 1959 [V—87]
31	970	5500±1500		Field, 1960 [V—106]
31	970		5.0	Radhakrishnan, 1961 [V—160]
31	970	5800	6.1	Roberts and Stanley, 1959 [V—174]
31.2	960	5900		Roberts and Komesaroff, 1965
43	700	12000±2000		Rzhiga and Trunova, 1965 [V—13]
48.5	620	12400	6.3	Roberts and Ekers, 1965 [V—171]
49	610	16000	2.6-7.0	Barber and Moule, 1963 [V—22]
49	610.5		5.2±1.0	Dickel, 1965 [V—70]
49	610		7.05±0.2	Barber, 1967 [V—19]
68	440	19000	5-13	Drake and Hvatum, 1959 [V—87]
68	440	70000±30000		Field, 1960 [V—105]
70	430	26000	6.3	Keyzes and Tiberti, 1965 [V—169]
70	430	26700	5.80±0.28	Hardebeck, 1964 [V—122]

CHARACTERISTICS OF JUPITER'S DECIMETRIC RADIO EMISSION (Continued)

λ, cm	μ, MHz	T_B, °K	Emission flux density (10^{-26} watt /$m^2 \cdot$Hz)	Author, year
1	2	3	4	5
70.16	428	20000±2600	4.9±0.5	Krotikov et al., 1965 [V—9]
73.5	408	28000	6.3	Roberts and Komesaroff, 1965 [V—173]
74	408		4.4±0.2	McAdam, 1964 [V—140]
154	195	120000	6.1	Keyzes, 1965 [V—1969]
168	178	86000	4.1	Cower, 1963 [V—66]

(3.5—7 R_J), one can draw the conclusion that magneto-bremsstrahlung of electrons in the radiation belts is the source of the decimetric radio emission. Synchrotron emission of relativistic electrons is the most probable source, as /90 is indicated in particular by the linear polarization of the decimetric emission.

DECAMETRIC RADIO EMISSION

Jupiter's decametric radio emission is of a sporadic nature and has the form of bursts whose duration varies within wide limits, ranging from several microseconds to several days.

CLASSIFICATION OF SOURCES OF DECAMETRIC EMISSION
(ACCORDING TO DOUGLAS AND SMITH [V—82])

Type	Duration	Main cause
Active periods	Days — weeks	Beating of the rotational periods of the Earth and Jupiter and the period of revolution of Io; possibly an intrinsic variation of Jupiter's surface activity.
Noise storms	Minutes-hours	Rotation of a directed emitter and the receiver.

CLASSIFICATION OF SOURCES OF DECAMETRIC EMISSION (Continued)

Type	Duration	Main cause
Groups of bursts	Seconds-minutes	Ionospheric scintillations
L-pulsations	0.1-5 sec	Interplanetary scintillations
S-pulsations	0.01-0.01 sec	Unknown

The power of the decametric radiation is $P \approx 10^8$ watts/Hz. The angular dimensions of the source of the bursts in the decametric region is from 3" to 15" according to the estimates of various authors.

The source of the decametric radio emissions, which have small angular dimensions, is either closely connected with the planet's surface or is located on the surface

Possible mechanisms for explaining the decametric radio emission are [V—4, 25, 77, 82, 103, 123, 229; I—31]:

1) rotation of Jupiter's magnetic field;

2) disturbances of the magnetosphere associated with the motion of Jupiter's satellite Io;

3) plasma oscillations in Jupiter's ionosphere;

4) chemical explosions in Jupiter's atmosphere;

5) cyclotron radiation of a beam of electrons in anomalies of Jupiter's magnetic field;

6) propagation of whistling atmospherics in Jupiter's magnetosphere;

7) Cerenkov radiation of electrons penetrating Jupiter's ionosphere;

8) coherent cyclotron radiation; and

9) electrical discharges in Jupiter's atmosphere.

CHARACTERISTICS OF THE DECAMETRIC RADIO EMISSION /91

λ, m	Density of radio radiation (watts/$m^2 \cdot Hz$)	Longitude of the sources (ω_{III})	Data on the polarization	Author, year
4.0-85.0	$2 \cdot 10^{-21}$-$2 \cdot 10^{-22}$	300°-50°,150°		Solomon, et al., 1966

CHARACTERISTICS OF THE DECAMETRIC RADIO EMISSION (Continued)

λ, m	Density of radio radiation (watts/$m^2 \cdot Hz$)	Longitude of the sources (ω_{III})	Data on the polarization	Author, year
11.0-60.0	10^{-18}-$2 \cdot 10^{-21}$	110°,212°,280°		Carr and Smith, 1962 [V—56]
11.4	10^{-22}	70°-190°, 190°--265°,265°-330°		Stone et al , 1964 [V—207]
12.5			Right-hand circular	Barrow, 1963 [V—26]
13.5-16.7	10^{-20}-10^{-19}		Elliptical with right-hand rotation	Barrow, 1963, [V—24, 25]
15.0		100°,200°,320°		Warwick, 1963 [V—225]
15.0		110°,230°,320°	Elliptical	Sherill, 1963 [V—184]
16.5			Linear	Barrow, 1957 [V—27]
16.7	$7.85 \cdot 10^{-21}$	2 localized sources		Barrow and Carr, 1957 [V—30]
62.5	10^{-22}-$2 \cdot 10^{-20}$			Ellis, 1961 [V—99]
64.0	$1.1 \cdot 10^{-21}$			Shysh, V. I., 1965 [V—14]
75		130°,240°,300°	Circular with variation of the direction	Warwick, 1965 [V—229]
1500	$3 \cdot 10^{-18}$			Shysh, V. I., 1965 [V—14]

EFFECT OF THE SATELLITES ON THE RADIO EMISSION

The satellite JI, Io (which has a circular orbit with a period of 42^d, $a = 6\ R_J$), exerts an effect on Jupiter's decametric radio emission, but it does not influence the radio emission in the centimeter region.

Bursts of radio radiation in the decametric region are observed when the line joining the centers of Jupiter and the Earth forms an angle of 90° and 240° with the direction Jupiter — Io and when the longitude of Jupiter's central meridian is $\omega_{III} = 100° — 170°$ and 200° — 270° [V—90, 91], respectively. At these moments the plane which passes through Jupiter's magnetic axis and its rotational axis is near the satellite. The position of the latter predetermines both the probability of the appearance of radio radiation bursts and their intensity [V—42].

It is possible that Io affects the total circulation of the planet's atmosphere or excites Alfvén waves, which change into plasma oscillations giving the bursts of radio radiation in the decametric region [V—145, 232]. /92

The bursts in the decametric region can be of two types: those which depend on the position of Io (L-bursts are broad-band — 500 kHz, with a duration from a second to several seconds), and those which do not depend on Io's position (S-bursts are narrow-band — 50 kHz, with a duration from several milliseconds to seconds) [V—17, 162].

Little is known of the effect of the other satellites. It is possible that the emission induced by satellites II—V has a high directionality and does not fall in the ecliptic plane and therefore can not be observed from the Earth. The periodicity of $3-4^d$ detected in the variation of the intensity of Jupiter's radio emission in the decametric region is connected with the 3.5^d syzygy of Io and JV, and the periodicity of $7-8^d$ may be associated with the 7-day syzygy of satellites I, II, and III [V—43, 186].

CHARACTERISTICS OF JUPITER'S MAGNETIC FIELD AND MAGNETOSPHERE ON THE BASIS OF THE RESULTS OF RADIO OBSERVATIONS

Magnetic field intensity at the equator, gauss	Magnetic field intensity at the pole, gauss	Inclination of the magnetic axis to the axis of rotation	Longitude of the northern magnetic pole, ω_{III}	Author, year
0.1-1	6-60			Chang and Davis, 1961 [V—60]
2	100			Field, 1961 [V—108]
6.4				Landovitz et al., 1962 [V—134]
		10°	195°	Gary, 1963 [V—112]
		9°		Morris and Berge, 1963 [V—154]
15		10°	0°	Ellis, 1963 [V—101]
			198°	Roberts and Komesaroff, 1964 [V—172]
		10°.1±1°	198°.2±2	Barber, 1966 [V—20]
0.3		11°.5	211°	Dickel, 1967 [V—71]
	50	11°		Hide, 1967 [IV—63]
		12°.5±1°.2	193°±3°.5	Davies et al., 1967 [V—67]
		10°.5±1°.6	180°±5°	Conway and Kronberg, 1967 [V—64]

The layout of the magnetosphere is schematically illustrated in Figure 51. /93

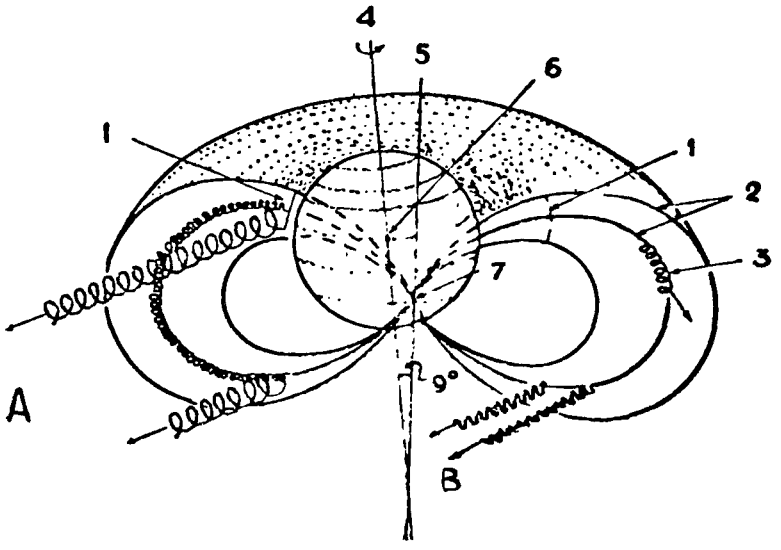


Figure 51. Scheme for the arrangement of Jupiter's magnetic field and radiation belts (according to Warwick): 1) mirror points; 2) lines of force of the magnetic field; 3) path of captured particles; 4) the planet's axis of rotation; 5) axis of the magnetic dipole; 6) center of mass; 7) magnetic dipole's center; A) circularly-polarized decametric radio emission; B) plane-polarized decimetric radio emission.

THE IONOSPHERE

The structure of Jupiter's ionosphere is still unclear. The positive ions H^+, H^+_2, He^+, and electrons evidently are the main components of the ionsphere. The altitude of the ionosphere is $\sim$ 500 km.

VALUES OF THE ELECTRON DENSITY n_e
ACCORDING TO THE ESTIMATE OF VARIOUS AUTHORS

n_e (cm^{-3})	Author, year
10^3	Ellis, 1963 [V—101]
$7 \cdot 10^5 - 4 \cdot 10^6$	Gross and Rasool, 1964 [IV—54]
$1.6 \cdot 10^7$	Shimizy, 1965 [IV—124]

VALUES OF THE ELECTRON DENSITY n_e ACCORDING TO THE ESTIMATE OF VARIOUS AUTHORS (Continued)

n_e (cm^{-3})	Author, year
$3 \cdot 10^5$	Zheleznyakov, 1965 [IV—14]
$3 \cdot 10^4$	Gordon and Warwick, 1966 [V—116]

THE RADIATION BELTS

/94

Observations of Jupiter's decimetric radio emission have permitted establishing that a region whose angular dimensions are much larger than the planet's disk is the source of the emission. It was concluded that Jupiter has two radiation belts, an inner one and an outer one; one is widely distributed in latitude and the second (the inner one) is strongly flattened towards the magnetic equator.

DIMENSIONS OF THE RADIATION BELTS

Dimensions of the outer belt (in the plane of the equator)	Dimensions of the inner belt (in the plane of the equator)	Author, year
6-7 R_J		Field, 1960b [V—106]
9-11R_J		Van Allen, 1960
6-7 R_J	1.6 R_J	McAdam, 1966 [V—140]
3 D_J	$(1.3 \pm 0.2) D_J$	Pariyskiy, 1963 [V—12]

According to Field's estimate [V—106], the electron concentration in the inner radiation belt is 1.6×10^{-2} cm^{-3}. The polar dimension of the radiation belts is approximately equal to Jupiter's diameter. The number of electrons is estimated to be 10^{28} with an energy of $\sim$ 10 Mev. The total emitting power is $\sim 10^{16}$ ergs/sec.

CORRELATION WITH SOLAR ACTIVITY AND WITH VISIBLE DETAILS OF JUPITER

A correlation of Jupiter's radio emission bursts with solar activity has been detected by many authors (Carr and Smith, 1960-1961 [V—195]; Warwick, 1962-1963 [V—221]; Barrow, 1962 [V—24]; Roberts, 1962 [V—168]; Six and Holmes, 1966 [V—186], and others): an agreement of the periodicity of the radio emission (7—8, 11—12, and 34—35 days) with solar activity (7—9, 10—11, and 32—35 days) has been noted which can serve as an argument in favor of the hypothesis that the radio emission bursts are produced by corpuscular fluxes of charged particles arriving from the Sun. Such a correlation confirms the existence of an ionosphere on Jupiter. All attempts to find a correlation of the radio emission with visible variations or details on the planet's disk have still given a negative result.

RADAR OBSERVATIONS OF JUPITER

/95

In 1963 radar observations were carried out in the Soviet Union of Jupiter at a frequency of 700 MHz (Kotel'nikova et al., 1964 [V—7]). It was discovered that Jupiter causes a strong blurring of the spectrum of the reflected signals, evidently becuase of its rapid rotation about its axis. The reflection coefficient of a radio signal from the planet was $\sim$ 10%.

An experiment to observe Jupiter by radar at a wavelength of 12.5 cm was carried out in the U.S.A. also in 1963 (Goldstein, 1964 [V—114]). A radio echo was not detected during observations through narrow-band filters but was recorded in individual cases in the 33 kHz band by means of the signal accumulation technique. It was noted that the appearance of a reflected signal correlates with System I of Jupiter's rotation and corresponds to a region of the planet with a diameter on the order of 100 km and a longitude of 32°. In 1964 an attempt was made at Arecibo to make a radar observation of Jupiter at a wavelength of 70 cm, but it proved to be unsuccessful.

Fesenkov and Masevich's Model (1951 [IV—27])

The van der Waals equation of state for molecular hydrogen at T = 140°K was used up to P = 100 atm, and for P > 100 atm, the Bartolome-Eiken equation of state. Since for P ∿ 700000 atm a phase transition of hydrogen and a density jump from 0.4 to 0.8 g/cm^3 should take place, two versions of the function P (ρ) were used for 700,000 < P < 10 million atm. For P > 10^7 atm the Scholte equation of state was assumed. As the initial approximation, a model planet was calculated with the mass of Jupiter and consisting of pure hydrogen. The first version is presented only in Figure 52. In this version the solution is characterized by the following data: $\frac{M_{core}}{M_0} = 0.329$; $\bar{A} = 6$; $\frac{R_{core}}{R_0} = 0.335$; $\bar{Z} = 3$; $\frac{J}{MR^2} = 0.22$, where A is the average atomic weight, $\bar{Z}$ is the charge, ρ is the density, and $J = \frac{B\pi}{3}\int_0^R \rho r^4\, dr$.

Jupiter should consist of a comparatively thin layer of molecular hydrogen (the layer's thickness is ∿ 15% of the radius, and its mass is ∿ 7% M_J), a layer of atomic hydrogen (a thickness of ∿ 55% and a mass of ∿ 65% M_J), and a core consisting of a mixture with an average atomic weight A = 5. The radius of the core is ∿ 30% and its mass is ∿ 25% of the planet's mass.

DISTRIBUTION OF MASS, PRESSURE, AND DENSITY WITH RADIAL DISTANCE IN THE PLANET (SECOND VERSION) /96

r/R_0	M/M_0	lgP	g/cm^3
core with $\bar{A}$=4, $\bar{Z}$=2			
0,000	0,000	+7,936	10,46
0,100			10,104
0,200			9,051
0,289	0,156	+7,58	6,958

DISTRIBUTION OF MASS, PRESSURE, AND DENSITY WITH RADIAL DISTANCE IN THE PLANET (SECOND VERSION)

(Continued)

r/R_0	M/M_0	$\lg P$	g/cm^3
	H_1 Zone		
0,259	0,156	+7,58	2,761
0,555	0,424	+7,05	1,972
0,719	0,691	+6,65	1,439
0,811	0,849	+6,25	1,062
0,862	0,927	+5,85	0,800
	H_2 Zone		
0,862	0,927	+5,85	0,400
0,917	0,961	+5,5	0,273
0,964	0,983	+5,0	0,200
0,984	0,996	+4,5	0,160
0,992	0,999	+4,0	0,133
0,996	1,000	+3,5	0,109
0,997	1,000	+3,00	0,090
0,998	1,000	+2,00	0,017
0,999	1,000	+1,00	0,002
1,000	1,000	−1,16	0,000

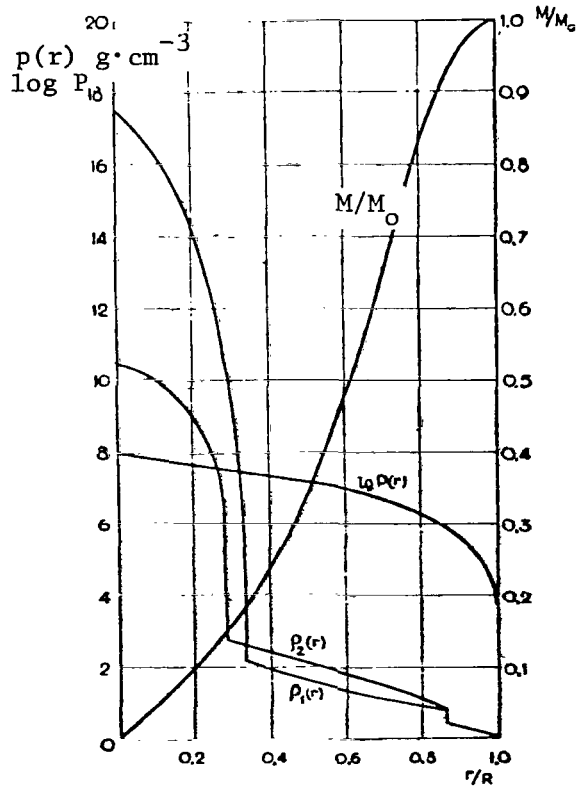


Figure 52. Jupiter's internal structure (according to Fesenkov and Masevich). Variation of the density (ρ), pressure (P), and mass (M/M_0) along the plante's radius.

Kozlovskoy's Model, 1956 [IV—18]

The Abrikosov, Ramsey, and Davydov equations of state were used:

Equation of state	Molecular hydrogen		Atomic hydrogen		Core	$\bar{\rho}$ of the core, g/cm^3	K	I/MR^2	N
	r/R	$\frac{M_{H_2}}{M}$	r/R	$\frac{M_{H}}{M}$	$\frac{M_{core}}{M}$				
Abrikosov	0,73	0,16	0,24	0,57	0,27	26	73	0,192	2,7
Ramsey	0,86	0,07	0,22	0,74	0,19	24	81	0,224	4,3
Davydov	0,82	0,14	0,19	0,76	0,10	18	90	0,247	9

K is the fraction of hydrogen (by mass) of the planet's total mass in %; and N is the amount of hydrogen in grams per gram of the other elements.

Dauviller's Model (1953 [IV—45]) /97

The planet consists of a central iron-nickel core, a lithosphere (mainly silicate), an "ocean" of a layer of ice (H_2O, H_2S), a layer of gaseous neon in which solid ammonia is floating, a layer of liquid methane, and a gaseous atmosphere. The variation of ρ with pressure is not taken into account.

The model is improbable.

Layer	Mass, %	ρ, g/cm^3	Thickness of the layer, cm
Core	16.6	8.0	$21 \cdot 10^8$
Lithosphere	16.1	3.5	$10 \cdot 10^8$
Ocean	67.3	1.0	$39 \cdot 10^8$

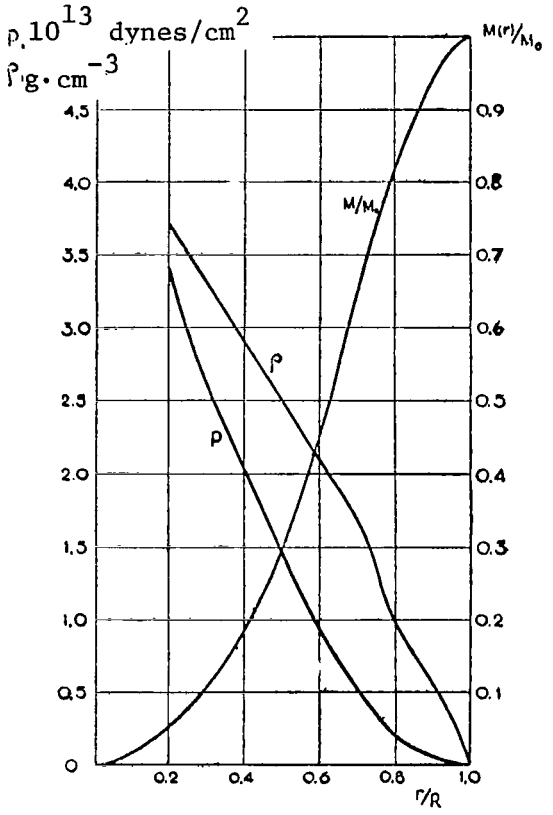


Figure 53. Jupiter s internal structure (according to Peebles).

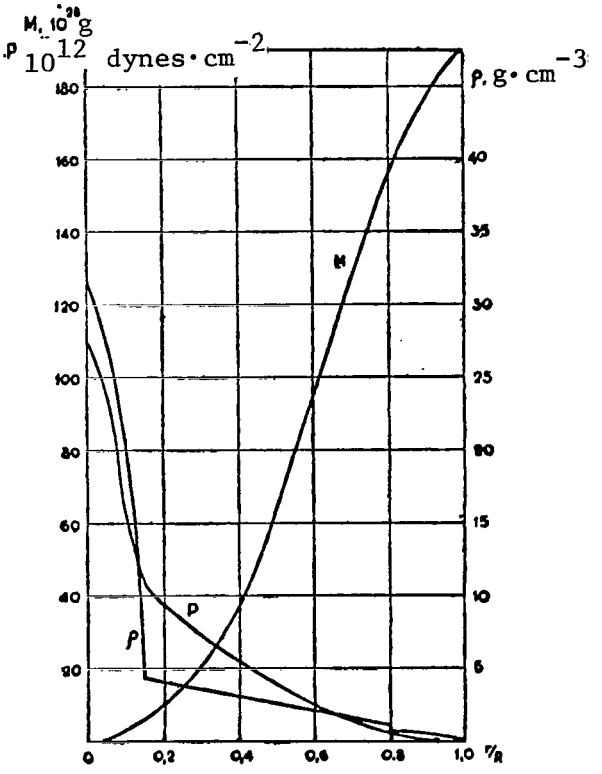


Figure 54. Jupiter's internal structure (according to DeMarcus).

Peebles' Model, 1964 [IV—99] (Figure 53) /100

The model supposes the existence of a central core of heavy elements, with a mass of the order of 10 Earth masses.

DISTRIBUTION OF THE PRESSURE, DENSITY, AND MASS ALONG JUPITER'S RADIUS

a) According to Peebles

r/R	P, 10^{12} dynes/cm^{-2}	ρ, g/cm^3	M/M_0
0,2	34	3,7	0,05
0,3	26	3,3	0,11
0,4	20,5	2,9	0,19
0,5	15,0	2,5	0,30
0,55	11,9	2,3	0,38
0,6	9,5	2,1	0,46
0,65	7,2	1,84	0,55
0,7	5,2	1,63	0,64
0,75	3,5	1,39	0,74
0,8	2,2	0,96	0,815
0,85	1,29	0,76	0,878
0,9	0,57	0,55	0,941
0,92	0,38	0,47	0,957
0,94	0,23	0,40	0,973
0,96	0,095	0,28	0,988
0,98	0,020	0,147	0,997
0,99	$2,8\cdot10^{-3}$	0,055	0,9996
0,995	$3,7\cdot10^{-4}$	0,0164	0,99995
1,00	$3,0\cdot10^{-6}$	$5,5\cdot10^{-4}$	1,00

b) According to DeMarcus

r/R	ρ, g/cm^3	M, 10^{27} g	P, 10^{12} dynes/cm^2
0	30,84	0	110
0,05	27,90	5,19	96,3
0,1	19,09	33,98	63,5
0,15	4,40	72,19	43,2
0,2	4,08	100,37	37,6
0,25	3,81	142,88	33,1
0,3	3,58	203,05	29,2
0,35	3,37	281,40	25,5
0,4	3,14	379,85	21,9
0,45	2,90	496,32	18,5
0,5	2,66	630,96	15,3
0,55	2,40	780,05	12,3
0,6	2,12	940,33	9,52
0,65	1,83	1105,11	7,12
0,7	1,56	1270,27	5,07
0,75	1,31	1431,29	3,37
0,800	1,09	1585,16	1,98
0,802	1,08	1591,13	1,93
0,802	0,777	1591,13	1,93
0,82	0,714	1628,92	1,62
0,86	0,593	1707,76	1,06
0,90	0,479	1778,72	0,614
0,94	0,367	1840,11	0,283
0,98	0,246	1888,49	0,0568
0,98942	0,197	1897,15	0,0200
0,98945	0,185	1897,15	0,0200
0,990	0,181	1897,60	0,0181
0,992	0,162	1899,04	0,0121
0,994	0,138	1900,31	0,0068
0,996	0,103	1901,34	0,0027
0,998	0,032	1901,92	0,00033
1,000	0,00016	1902,0	0,00

DeMarcus' Model, 1958 [IV - 80, 81] (Figure 54)

The model is based on interpolated equations derived by DeMarcus for helium and molecular hydrogen and on the calculated characteristics of metallic hydrogen. It is shown that there is more than 78% hydrogen by mass in Jupiter. According to this model, the distribution of density, mass, and pressure is found to be the following (see the Table on page 99*).

*Translator's Note: This corresponds to English page 97.

DIMENSIONS

The data on dimensions refer to the visible surface of Saturn's cloud layer.

Angular Dimensions at a Distance of 1 A.U.

Average diameter	$\bar{D}''$	159".22 ± 0".58
Equatorial diameter	D''_{eq}	164".92 ± 0".45
Polar diameter	D''_{polar}	147".83 ± 0".85

Linear Dimensions

Average diameter	$\bar{D}$	115,420 ± 400 km = 9.06 ± 0.03 D_E
Radius	$\bar{R}$	57,710 km
Equatorial diameter	D_{eq}	119,550 ± 300 km
Radius	R_{eq}	59,775 km
Polar diameter	D_{polar}	107,170 ± 600 km
Radius	R_{polar}	53,585 km
Optical oblateness	ε_{opt}	0.103 (1:9.74)
Volume (V_E = 1)	V_S	743
Dynamical oblateness	ε_{dyn}	0.09792

MASS AND GRAVITATIONAL ACCELERATION

Mass	M_S	$5.678 \cdot 10^{29}$ g
	(M_E = 1)	95.030 ± 0.006

	$\frac{M_\odot}{M_S}$	3498.70 ± 0.24
Average density	$\bar{\rho}_S$	0.705 ± 0.008 g/cm^3
Acceleration due to gravity (without taking rotation into account)	g_S	1138 cm/sec^2
	g_S/g_E	1.16
At the equator, taking centrifugal force into account	g_{eq}	958 cm/sec^2
	g_{eq}/g_E	0.98
Escape velocity at the surface		36.6 km/sec

Rotation

/102

Saturn's visible surface has a zonal type of rotation, just as Jupiter has. However, the periods of rotation cannot be determined exactly because of the absence of sufficiently distinct details in the planet's cloud layer. The period of rotation of the equatorial zone is 10 hrs 14 min. The period of rotation of temperate latitudes is 10 hrs 38 min.

According to V. V. Sharonov (1958 [I - 12])

Latitude zone	Period of rotation
0—10°	10^h12^m—10^h16^m
10—20°	10 15 —10 20
35—40°	10 36 —10 38
57°	11 00 —11 15

OPTICAL CHARACTERISTICS

Here some average characteristics of the optical properties of Saturn's disk are presented. The ring differs significantly in optical properties from the planet's disk and exerts a significant influence on its integral brightness, color, and other parameters as a function of the degree of opening for the terrestrial observer.

BRIGHTNESS, ALBEDO, AND POLARIZATION OF SATURN'S DISK

Parameters	Value	Author, year	Note
Integral stellar magnitude	$\bar{V}(1.0) = -8^m.82$ to $8^m.94$	Harris, 1963 [I-6]	Without the ring
Apparent stellar magnitude at the epoch of mean opposition	$\bar{V} = +0^m.67$	"	"
Equation for reducing the brightness to the brightness without the rings	$\Delta V = +2^m.60 \sin B - 1.25 \sin^2 B$	Harris, 1963	B is the angle of inclination of the plane of the rings
Albedo:		Harris, 1963	
Geometric	P(U) = 0.211 P(B) = 0.316 P(V) = 0.461		
Spherical	$A_V = 0.76$		
Phase integral	$g_V = 1.65$		Tentative
Range of phase angle change	0°.0 - 6°.5		
Polarization:	0.01	Lyot, 1924	
Entire disk	to 0.005	Bolkvadze, 1967 [II-16]	Without the ring
Center of the disk	to 0.036	"	
Polar regions	to 0.117 (S) to 0.063 (N)	" "	

COLOR CHARACTERISTICS /103

The value of Saturn's color index can vary significantly with time due to the variation in the degree of opening of the ring. On the basis of the data of spectral and photometric measurements, the ring is noticeably bluer than the planet's disk. On the basis of old colorimetric observations, the integral color index lies in the renge $+1^m.02$ to $+1^m.23$.

COLOR INDICES (SPECTRAL MEASUREMENTS) BASED ON THE DATA OF V. G. TEYFEL' AND YA. A. TEYFEL' (1957 [III - 36, 37])

Object	CI	CI - CI_0
W. part of the ring	$+0^m.83$	$-0^m.45$
E. part of the ring	+0 .76	-0 .52
W. edge of the disk	+1 .27	-0 .01
E. edge of the disk	+1 . 22	-0 .06
Center of the disk (CI_0)	+1 .28	-

SPECTRAL REFLECTIVITY

Relative Spectral Variation of the Reflectivity

The spectral variation of the reflectivity of the center of Saturn's disk with respect to the Sun ($B_s/B_\odot$) is presented according to the measurements of G. A. Shajn (photographic spectrophotometry) and V. N. Lebedinets (photographic photometry) in relative units.

λ, Å	Spectral observations (Shayn, 1933 [III-43])	Photographic photometry (Lebedinets, 1953 - 1954 [II-26])
4290	—	1,000
4330	1,000	—
4560	1,148	—
4810	1,318	—
5115	1,871	—
5210	—	1,959
5530	2,249	—
5940	—	2,377
6370	2,938	—
6480	—	2,626

In 1961 G. Münch and R. Younkin (1963 [III - 76]) performed photoelectric /104 spectrophotometry of Saturn, measuring the distribution of relative intensity across the spectrum in a region of the disk between the pole and the inner edge

of part of the ring projected onto the disk. The spectral curves are shown in Figure 55.

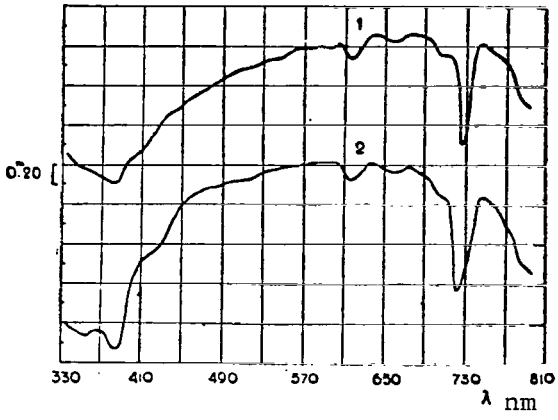


Figure 55. Relative spectral reflectivity (1) and relative energy distribution (2) in Saturn's spectrum (according to Münch and Younkin).

Rocket Measurements in the Ultraviolet

R. Bless, A. Code, and D. Taylor (1968 [II - 45a]) measured Saturn's reflectivity in the region λλ 2450 - 2950 Å with the help of a photometer mounted on an Aerobee rocket. Depending on whether or not Saturn's rings are assumed to be non-reflecting or supplementary contributors to the planet's brightness in proportion to their relative area projected onto the celestial sphere, two values of the geometric albedo (P and P', respectively) are found:

λ, Å	Flux, 10^{-10} ergs/cm^2 · sec · Å	P	P'
2450	0,68 ± 0,25	0,44	0,31
2800	1,9 ± 0,7	0,40	0,27
2950	4,3 ± 0,9	0,34	0,24

Brightness Distribution Across the Disk /105

As of the present very few reliable photometric investigations of Saturn's visible surface have been carried out, and there have been practically no attempts to determine the optical parameters of its cloud layer.

DISTRIBUTION OF RELATIVE BRIGHTNESS ALONG SATURN'S INTENSITY EQUATOR (LEBEDINETS, 1957 [II—261])

Period of observations	1953				1954			
	λ_{eff}, nm							
r/R	648	594	521	432	648	594	521	432
0.00	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.10	0.994	0.992	0.995	0.994	0.981	0.994	0.998	0.993
0.20	0.980	0.972	0.976	0.984	0.969	0.984	0.994	0.997
0.30	0.960	0.950	0.967	0.966	0.925	0.964	0.978	0.961
0.40	0.934	0.900	0.940	0.937	0.884	0.932	0.951	0.936
0.50	0.875	0.847	0.902	0.897	0.831	0.883	0.907	0.902
0.60	0.784	0.778	0.843	0.850	0.762	0.794	0.838	0.863
0.70	0.674	0.672	0.759	0.787	0.672	0.700	0.735	0.809
0.80	0.512	0.544	0.628	0.712	0.541	0.560	0.616	0.727

V. N. Lebedinets determined in addition by means of absolute photometry the brightness coefficients of the central portion of Saturn's bright equatorial belt in 1953 - 1954: λ = 648 nm, ρ = 0.608: λ = 594 nm, ρ = 0.550; λ = 521 nm, ρ = 0.456; λ = 432 nm, ρ = 0.232.

More recent measurements of the brightness distribution across Saturn's disk cannot be considered reliable because of the very small dimensions of the photographic images.

In 1961 M. Bellier et al. (1963 [II - 43]) took photographs of Saturn with the help of a Lallemand electronic camera. The brightness distribution along the planet's intensity equator and the rings which they found are shown in Figure 56.

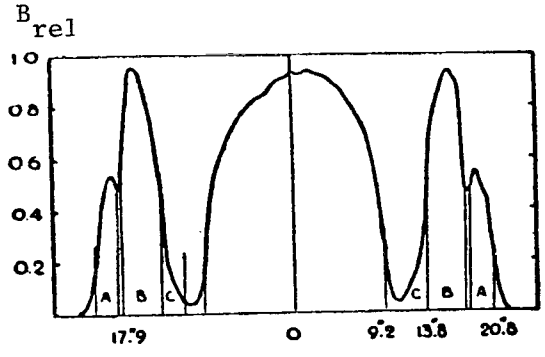


Figure 56. Variation of relative brightness along Saturn's intensity equator in 1961 (according to Bellier and Dupré, observations with an electronic camera). Rings A, B, and C are marked.

During 1966 when the rings and the plane of Saturn's equator were oriented on edge with respect to the Earth, photography and photometry of the planet were carried out by M. Marin (1968 [II - 87a]) at various wavelengths, including the ultraviolet (Figures 57, 58). Two distinctive features of Saturn's disk in the ultraviolet call attention to themselves: the darkening of the equatorial region, which appears bright in yellow and red light, and the increase in the brightness towards the edges of the planet's disk at all latitudes, with the exception of the polar regions.

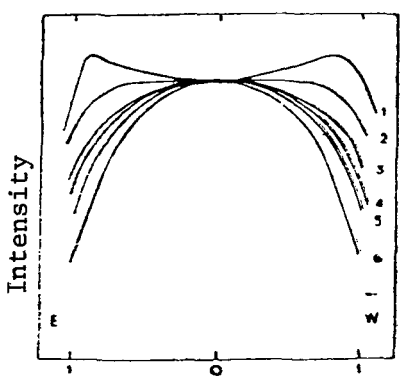


Figure 57. Variation of relative intensity along Saturn's equator at various wavelengths in 1966 (according to Marin). The effective wavelengths are:

1 - 3550 Å; 2 - 3950 Å; 3 - 4300 Å; 4 - 4720 Å; 5 - 5870 Å; 6 - 6250 Å.

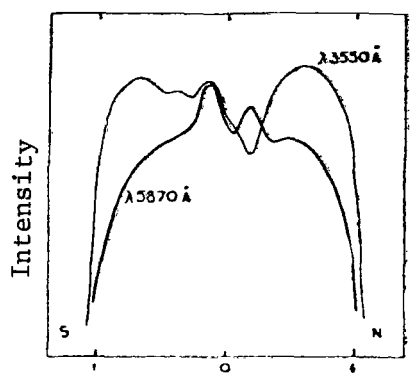


Figure 58. Variation of relative intensity along Saturn's central meridian in 1966 (according to Marin).

MOLECULAR ABSORPTION BANDS IN THE SPECTRUM

/107

At the present time the presence in Saturn's spectrum of absorption bands of only two gases which enter into the composition of this planet's atmosphere has been rigorously established: methane (CH_4) and molecular hydrogen (H_2). The methane and hydrogen absorption bands in Saturn's spectrum are noticeably more intense than in Jupiter's spectrum. The problem as to whether ammonia is present in Saturn's atmosphere remains unresolved.

Methane

CH_4. VISIBLE REGION OF SATURN'S SPECTRUM

λ, Å	Frequency interpretation	Eq. width, W, Å
5428	$7\nu_3$	
5762	$6\nu_3$	
6190	$5\nu_3+\nu_4$	23—31
6677		
6812	$5\nu_3$	
7020		
7190	$11\nu_4$	
7250	$4\nu_1+\nu_2$; $3\nu_1+2\nu_3$	70—110
7500		
7820	$3\nu_1+\nu_3+\nu_4$; $2\nu_1+\nu_2+\nu_4$	

CH_4. INFRARED REGION OF SATURN'S SPECTRUM

λ, μ	Frequency interpretation
1.00	$2\nu_1+\nu_2+\nu_3$; $\nu_1+\nu_2+2\nu_3$
1.12—1.09	$2\nu_1+\nu_3$; $2\nu_1+2\nu_3$; $3\nu_3$
1.15—1.18	$2\nu_1+\nu_3$; $\nu_1+2\nu_3$
1.33	$\nu_2+2\nu_3$
1.67	$2\nu_3$
1.72	$\nu_1+\nu_2+\nu_4$; $\nu_2+\nu_3+\nu_4$
2.20	$\nu_2+\nu_3$
2.32	$\nu_3+\nu_4$
2.38	$\nu_1+\nu_4$
2.42	$\nu_2+\nu_4$

Ammonia

Data on the presence in Saturn's spectrum of the NH_3 6450 Å absorption band are contradictory. Kuiper, Dunham, and also Bugayenko, Galkin, and Morozhenko have detected traces of absorption in this region. However, Spinrad, Owen, Münch, and Younkin consider that this band is not present and that the individual absorption lines observed near λ 6450 Å belong to methane. The NH_3 absorption bands in the 9800 - 11,200 Å region have not been detected in Saturn's spectrum; according to Kuiper's and Moroz's observations, the NH_3 1.53 μ band, which is strong in Jupiter's spectrum, is also absent. Evidently ammonia is contained in extremely small amounts in the upper zone of Saturn's atmosphere which is accessible to spectral observations.

Hydrogen

The equivalent width of the S (0) 6435.03 Å and S (1) 6367.80 Å lines of the (4 - 0) quadrupole band of H_2 are, according to Giver and Spinrad (1966

[III - 66]), as follows:

/108

W, mÅ		Zone of the disk
S (0)	S (1)	
16 ±5	16 ±4	Temperate latitudes
7 ±3	9 ±3	Edge of the disk
13,5±3	11,5±3	Equator
7,7±2	11,0±3	Equator

According to V. Tanaka's measurements (1968 [III - 110]), the equivalent width W of the S(1) line of the (3 - 0) band of H_2 is equal to 78 - 89 mÅ in the center of Saturn's disk. According to Owen (1969 [III - 88a]), W = 65 ± 10 mÅ for this same line, and the equivalent width of the S(0) and S(1) lines in the (4 - 0) band of H_2 are equal to 11.1 ± 5 mÅ and 11.9 ± 3 mÅ, respectively.

DISTRIBUTION OF MOLECULAR ABSORPTION ACROSS THE DISK

S. Hess found in 1953 [III - 65] that the CH_4 6190 Å absorption band on Saturn's disk is strengthened at latitudes of 45 - 55° (W = 27 - 28 Å) with respect to the equator (W = 23 Å). Subsequently, similar results were obtained by V. V. Avramchuk (1968 [III - 3a]) and N. A. Kozyrev (1969 [III - 13a]). According to the recent investigations of V. G. Teyfel' and G. A. Kharitonova (1970), absorption in the CH_4 6190 Å band decreases somewhat towards the edges of the disk at the equator but is strengthened with increasing latitude (Figure 59), although a tendency to decrease is detected in the polar regions. The least absorption is observed at the planet's bright equatorial belt, while it increases sharply in the neighboring temperate belt. This behavior can be explained by the fact that the bulk density of the aerosol layer at the equator is approximately 1.5 times greater than in temperate latitudes. The CH_4 7250 Å (V. G. Teyfel', 1969 [III - 113a]) and CH_4 8900 Å (T. Owen, 1969 [III - 88a]) bands increase in strength with latitude.

/109

RADIATIVE TEMPERATURE

The theoretically calculated radiative equilibrium temperature of Saturn's surface depends on the planet's distance from the Sun (on the value of the solar constant) and on its radiative peculiarities (absorption and reflection of solar radiation, emission coefficient in the thermal region). The solar constant at Saturn's average distance from the Sun (9.539 A.U.) is equal to $S_S = 0.02$ cal/cm^2. min.

ESTIMATES OF SATURN'S EQUILIBRIUM TEMPERATURE

T, °K	Author, year	Note
76	Kuiper, 1952 [I - 20]	For $A_{vis} = 0.50$
80	Moroz, 1967 [I - 9]	For $A_{int} = 0.50$
111	Pettit, 1963 [I - 10]	For $A_{vis} = 0.42$
89	Low, 1964 [III - 69]	
77	Aumann et al., 1969 [III - 47b]	For $A_{vis} = 0.45$

RADIOMETRIC TEMPERATURE

The radiometric temperature is determined from measurements of the planet's thermal emission in the radiometric transparency window of the terrestrial atmosphere (λλ 8 - 14 μ):

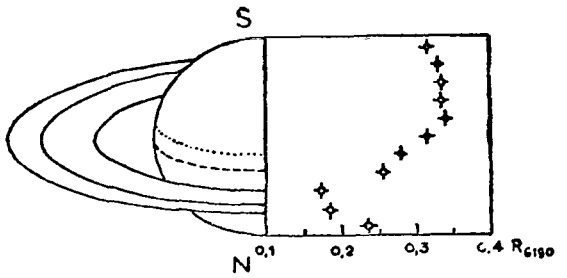


Figure 59. Variation of the depth R of the CH_4 6190 Å absorption band along Saturn's central meridian in 1969 (according to Teyfel' and Kharitonova).

T, °K	Author, year	Note
125	Pettit and Nicholson, 1963 [I - 10]	
120	Menzel, Coblentz, and Lampland, 1926	
85 ± 2	Low, 1964 [III - 64]	By comparison with Jupiter with T_J = 126 ± 2° K
93 ± 3	Low, 1964 [III - 64]	
100	Murray and Wildey, 1963 [III - 78]	Comparison with the Moon
107 (+5 - 10)	Moroz, Vasil'chenko, Davidyants, and Kaufman	

On the basis of observations from an airplane, H. Aumann, K. Gillespie, and F. Low (1969 [III - 47b]) estimated Saturn's effective temperature to be 97 ± 4° K in the λ 1.5 - 350 μ region. This value corresponds to an outflow of heat 2.5 times greater than the planet receives from the sun. /110

ROTATIONAL TEMPERATURE

The results of determining the rotational temperature from the relative intensity of rotational lines are of a preliminary nature. Because of the effect of multiple scattering in the cloud layer, it is still not clear to what level the derived temperature refers. The rotational temperature was calculated from the ratio of the intensities of the quadrupole lines S (1) and S (0) of hydrogen in the (3 - 0) and (4 - 0) bands:

Author, year	Line	T_{rot} (°K)
Spinrad, 1964 [III - 103]	H_2 (3.0) S (1)/S (0)	∿88
Spinrad and Giver, 1966 [III - 104] (on the basis of various spectrograms)	H_2 (4.0) S (1)/S (0)	126 ± 30 103 ± 20

CHEMICAL COMPOSITION OF THE OUTER ATMOSPHERE

The data on the chemical composition of Saturn's atmosphere are based on a comparison of the intensities of absorption bands of methane and hydrogen in the planet's spectrum with laboratory spectra. In making quantitative estimates of the gas contents, one usually employs a simple scattering model in which Saturn's cloud layer is assumed to be a continuous reflecting screen, and it is assumed that molecular absorption arises only in the outer atmosphere. Since it is actually necessary to take into account absorption inside the aerosol layer, the estimates of the gas contents obtained from the simple scattering model should be considered to be probable upper limits

ESTIMATES OF GAS CONTENTS IN SATURN'S ATMOSPHERE

Author, year	H_2, km-atm	CH_4, m-atm	NH_3, cm-atm
Kuiper, 1952 [I - 20]	-	350	<250
Spinrad, 1964 [III - 103]	40	-	none
Owen, 1969 [III - 88a]	190 ± 40	350	-
Moroz, 1967 [I - 9]	-	-	≤ 50
Tanaka, 1968 [III - 110]	70 = 300*	-	-

*The first estimate applies if the H_2 lines are not saturated, and the second estimate applies in the case of saturated lines.

R. Bless, A. Code, and D. Taylor (1968 [II - 45a]) estimate the H_2 content above the aerosol layer to be approximately 25 km-atm on the basis of rocket photometry data of Saturn at λλ 2400 - 2900 Å. 111

MODELS OF THE STRUCTURE OF THE OUTER ATMOSPHERE

Kuiper's Model, 1952 [I—20] (Figure 60)

Parameter	Value
Equilibrium temperature	$T_r = 76°$ K
Temperature of the isothermal stratosphere	$T_s = 64°$ K
Average molecular weight	$\bar{\mu} = 3.26$
Altitude of the tropopause above the surface of the cloud layer	$Z_T = 50$ km
Adiabatic temperature gradient in the supracloud troposphere.	$\Gamma_a = 1.8°$ K/km
Temperature at the surface of the cloud layer	154° K
Pressure at the surface of the cloud layer	$P_0 = 2$ atm
Altitude of the effective emission level in the radiometric region (T = 127° K) (from the surface of the cloud layer)	$Z_r = 11$ km

Trafton's Model (1967 [IV—131])

Trafton considered pure hydrogen models with various values of the effective temperature (T_e) and with H_2 absorption which depends on the wavelength in the thermal infrared spectral region (Figures 61 - 63). The /112 equilibrium temperature (T_B) is assumed to be equal to 89° K.

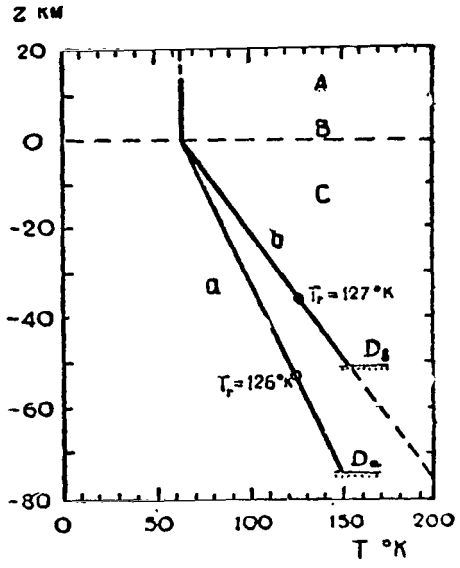


Figure 60. Variation of temperature with altitude in Saturn's atmosphere (Kuiper's models "a" and "b"). A - stratosphere; B - tropopause; C - troposphere; and D - cloud layer.

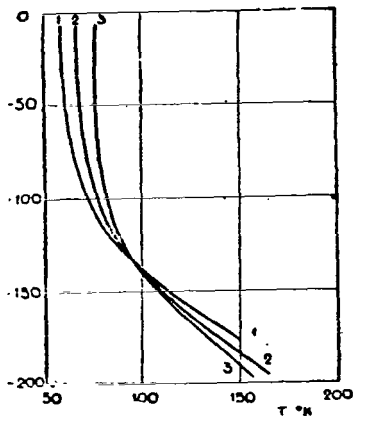


Figure 61. Variation of temperature with altitude in Saturn's atmosphere (according to Trafton). He:H_2 = 0:1; 1 - T_e = 80° K; 2 - T_e = 90° K; and 3 - T_e = 100° K.

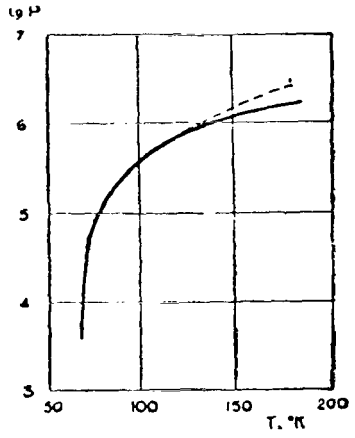


Figure 62. Pressure-temperature dependence in Saturn's atmosphere (according to Trafton) for a model with T_e = 90° K. The dashed curve takes convection into account.

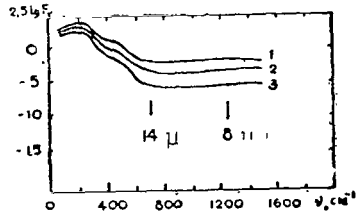


Figure 63. Spectral curves of Saturn's monochromatic thermal emission fluxes (according to Trafton): 1 - T_e = 100° K; 2 - T_e = 90° K; 3 - T_e = 80° K.

Parameter	I	II	III
He/H	0	0	0
NH_3/H_2	0.0002	0.0002	0.0002
CH_4/H_2	0.006	0.006	0.006
Effective temperature, T_e (°K)	100	90	80
Temperature of the isothermal stratosphere, T_S (°K)	76.8	68.3	60.0
Average optical thickness of the boundary of the convective zone	3.5	3.5	3.7
Temperature at the upper boundary of the convective zones, T_0 (°K)	118	105	91
H_2 content above the cloud layer, km-atm	52	52	55
Temperature gradient in the convective zone, Γa (°K/km)	1.0	1.2	1.2

TEMPERATURE OF THE EXOSPHERE

/113

Theoretical estimates of the temperature of Saturn's exosphere above the mesopause have been made by W. McGovern [IV - 83a] on the basis of the same assumptions as to the heating and cooling mechanism which he assumed in the case of Jupiter. The level of the mesopause corresponds to a density of 10^{14} cm^{-3}. The following values are obtained for the temperatures:

Composition of the atmosphere near the mesopause, %			Temperature of the exosphere, °K	
			At minimum solar activity	At maximum solar activity
H_2	He	C_2H_6		
59.80	39.90	0.30	109 - 119	128 - 163
59.98	39.99	0.03	110 - 120	131 - 172

SATURN'S RINGS

A characteristic distinctive feature of Saturn is its system of rings which lie in the plane of the planet's equator. The rings, like the equator, are inclined to the ecliptic plane at an angle of 28°.1 (the inclination to the plane of Saturn's orbit is 26°.7).

STRUCTURE OF SATURN'S RINGS

Ring	Ratio of the rings diameter to the planet's equatorial diameter	Diameter	
		In seconds of arc at mean opposition	In km
Ring A:			
Outer edge	2.25	43.96	275,000
Inner edge	1.98	38.69	240,000
Cassini's division (5000 km in width)			
Ring B:			
Outer edge	1.95	37,80	233,000
Inner edge	1.50	29.24	181,000
Gap between rings B and C (1600 km in width)			
Ring C:			
Inner edge*	1.24	24.12	149,400
Saturn (equatorial diameter)	1.00	19.52	120,800
Saturn (polar diameter)	0.89	17.46	108,000

*In 1969 P. Guerin at the Pic du Midi Observatory discovered one more inner ring (D) which is very faint and is separated from Ring C by a dark gap (Sky and Telescope, 1970, Vol. 40, No. 2, p. 88).

MASS OF RINGS (ACCORDING TO BOBROV, 1967 [IV—11]

/114

Limit	Mass of the rings	
	In grams	In fractions of Saturn's mass
Lower	$2 \cdot 10^{21}$	$4 \cdot 10^{-9}$
Upper	$2 \cdot 10^{23}$	$4 \cdot 10^{-7}$

At present the phase curve of Saturn's Ring B, which is distinguished by a sharply-expressed nonlinearity in its variation in the range of phase angles from 0° to 2°, is well-known. This property of Ring B is associated directly with the dimensions of the ring particles and the geometry of their surface layer.

The average phase curve of Saturn's Ring B (on the basis of the observations of Hertzsprung, Schoenberg, and Lebedinets) is presented in Figure 64. The brightness of the eastern I_E and the western I_W portions of Saturn's ring is not the same according to the data of many authors. According to Shenberg, $I_W/I_E = 1.04$. The radial distribution of the relative brightness along the rings is shown in Figure 65.

RATIO OF THE SURFACE BRIGHTNESSES OF THE WESTERN AND EASTERN PARTS OF SATURN'S RINGS, ACCORDING TO FURDYLO (1941 [II—33])

Year	λ_{eff}=640 nm	λ_{eff}=461 nm
1932	1,04	1,07
1934	1,42	1,04
1935	1,50	1,07
1936	1,12	1,29
1937	1,21	1,07
1938	1,00	1,14
Average	1,20	1,11

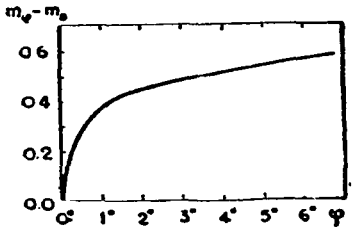


Figure 64. Variation of the brightness of Saturn's ring B with phase angle (an average curve based on the observations of Hertzsprung, Schoenberg, and Lebedinets).

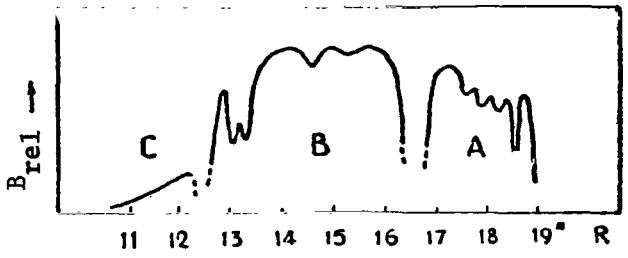


Figure 65. Photometric profile of Saturn's Rings A, B, and C (according to Dollfus).

M. S. Bobrov (1967 [IV - 11]) proposed parameters for the structure of Saturn's rings which satisfied the observations well enough, while simultaneously permitting a rather broad dispersion in the size distribution of the particles (see the Table on page 116*).

SOME PARAMETERS OF SATURN'S RINGS

Parameter	Value	Author, year	Note
Absorption bands in the ring spectrum	There are no absorption bands in the visible and photographic infrared region.	Shajn, G. A., 1935 [III - 43]	
	1.4 μ absorption bands	Shnyrev, Grechushnikov, and Moroz, 1964 [III - 44]	The band is wider at the ring than at the center of the disk with intensification of the long-wave limb.
	1.5 μ absorption bands	Shnyrev, Grechushnikov, and Moroz, 1964 [III - 44]	The intensity of the band is less in the ring spectrum than in the disk

*Translator's Note: This is on English page 132.

SOME PARAMETERS OF SATURN'S RINGS (Continued)

Parameter	Value	Author, year	Note
			spectrum, which agrees with the assumption that the particles are of an icy nature.
Phase integral	0.6		
Spherical albedo	0.30		
Radiative temperature	50 - 90° K	Mertz and Coleman, 1966 [III - 72]	
Albedo of the particles of Ring B	0.17 - 0.28	Bobrov, 1967 [IV - 11]	For various indicatrices and in the case of the validity of a ring model with a thickness of one particle.
	0.72	Sharonov, 1936 [II - 49]	
	0.61	Camichel, 1958	
	0.6	Bobrov, 1959 [IV - 8]	
Polarization Ring A:			
western end	0.001 - 0.005	Dollfus, 1963 [I - 7]	
eastern end	0.004 - 0.005	"	
Edge of the ring	Up to 0.15	Bolkvadze, 1967 [II - 16]	The polarization is always greater at the western edge than at the eastern edge. /116
Nature of the particles	Ice or covered with a layer of ice (hoarfrost)	Kuiper, 1952 [I - 20]	From a comparison of the spectrum of ice and the spectrum of Saturn's rings in the λλ 1.4 - 1.8 μ region

SOME PARAMETERS OF SATURN'S RINGS (Continued)

Parameter	Value	Author, year	Note
	Large particles covered with thin hoarfrost crystals	Moroz, 1967 [I - 9]	On the basis of Saturn's spectrum in the λλ 2 - 2.5 μ region.
	Solid formaldehyde	Mertz and Coleman, 1966 [III - 72]	On the basis of observations at the λλ 1 - 2.5 μ infrared region of the ring spectrum.

MODELS OF SATURN'S RINGS (ACCORDING TO BOBROV)

Parameters	Model I	Model II
Fraction of the ring volume occupied by particles	$5.00 \cdot 10^{-3}$	$4.32 \cdot 10^{-2}$
Lower limit of the particle radii	$1.00 \cdot 10^{-4}$ cm	4.28 cm
Upper limit of the particle radii	$7.50 \cdot 10^{-2}$ cm	$2.85 \cdot 10^{4}$ cm
Minimal radius of the particles which participate in the shadow effect	$2.00 \cdot 10^{-1}$ cm	4.28 cm
Optical thickness	1	1
Thickness of the ring	$1.00 \cdot 10^{5}$ cm	$1.00 \cdot 10^{5}$ cm

/117

SIZE OF THE PARTICLES

Author, year Author, year	Size of the particles	Thickness of the ring	Note
Shenberg, 1933	4 μ		Shenberg's theory seems unsatisfactory

SIZE OF THE PARTICLES (Continued)

Author, year	Size of the particles	Thickness of the ring	Note
Seeliger, 1884 - 1895	1 μ		The finite angular dimensions of the Sun were not taken into account in the calculations. Such an approximation is too coarse.
Franklin and Cook,	0.1 cm		The finite thickness of the ring is explained by an accumulation on the particles of an electrostatic charge which can be produced upon their collision with electrons.
Franklin, 1962	200 μ	10 cm	Determined from a calculation of the effect of diffraction by the particle on the length of its shadow.
Bobrov, 1956 [IV - 7]			
lower limit	10 cm	100 cm	Determined from the effect of mutual shadowing of the particles with account taken of the Sun's finite angular dimensions.
upper limit	10 m	10 km	
Kiladze, 1967 [II - 22]		1.42 ± 0.49 km	Determined on the basis of the minimum value of the ring brightness (an assumption as to the isotropicity of the light reflected by the rings).
Focas and Dollfus, 1969 [II - 63a]		2.8 ± 1.5 km	

Thus the estimates of the sizes of the ring particles and its thickness are still very scarce and contradictory.

RADIO EMISSION

Saturn's brightness temperature T_B in the radio region increases with wavelength, but far more slowly than is the case for Jupiter. The summary presented here of the measurements of T_B are taken from the paper of S. Gulkis, T. McDonough, and H. Draft (1969 [V - 120a]).

Saturn's radio emission flux density at a wavelength of 6 cm is 0.63×10^{-26} watt/$m^2 \cdot$Hz [V - 127]. A difference in the brightness temperatures has been noted in the case of observations at λ 9.4 cm with an orientation of the electric vector in the north-south direction ($T_B = 213 \pm 26°$ K) and the east-west direction ($T_B = 141 \pm 23°$ K), which indicates a significant polarization of the radiation of about $20 \pm 8\%$ [V - 178, 179]. Other authors do not confirm such a high polarization of the radiation; they estimate it to be less than 6%. /118

SATURN'S MICROWAVE SPECTRUM

λ, cm	T_B, °K	Author, year
0.12		Low and Davidson, 1965
0.32	97(+52, -42)	Tolbert, 1966 [V - 215]
0.34	130 ± 15	Epstein, 1968
0.43	103(+70, -64)	Tolbert, 1966 [V - 215]
0.80	132 ± 9	Salomonovich, Kutuza, and Losovskiy, 1965 [V - 10]
0.86	116 ± 30	Tolbert, 1966 [V - 215]
0.955	118 ± 20	Hobbs, 1968
1.53	146 ± 23	Welch and Thorton, 1965
1.53	141 ± 15	Welch, Thornton, and Lohman, 1966 [V - 231]

λ, cm	T_B, °K	Author, year
1.90	200 ± 30	Kellerman and Pauliny-Toth, 1966
3.12	123 ± 16	Berge, 1968
3.45	106 ± 21	Cook, Cross, Bair, and Arnold, 1960 [V - 65]
6.0	179 ± 19	Kellerman, 1966 [V - 127]
6.0	190 ± 45	Hughes, 1966 [V - 125]
9.0	165 ± 25	Berge and Read, 1968 [V - 41a]
9.4	177 ± 30	Rose, Bologna, and Sloanaker, 1963 [V - 178, 179]
10.0	196 ± 44	Drake, 1962
10.7	172 ± 20	Berge and Read, 1968 [V - 41a]
11.3	196 ± 20	Kellerman, 1966 [V - 127]
11.3	182 ± 20	Davies, Bird, and Cooper, 1964
21.2	286 ± 37	Davies and Williams, 1966 [V - 67]
21.3	303 ± 50	Kellerman, 1966 [V - 127]
70.0	1250*	Gulkis, McDonough, and Kraft, 1969 [V - 120a]

*Radio emission was not detected.

An analysis of the observations and theoretical calculations has shown [V - 120a] that a thermal nature is the most probable for Saturn's radio emission, which is formed in the planet's atmosphere and emerges from deeper (hotter) layers of the atmosphere with increasing wavelength.

The question as to the existence of a magnetic field on Saturn still remains unexplained.

INTERNAL STRUCTURE

Kozlovskaya's Model (1956 [IV—18])

The equations of state according to Abrikosov, Ramsey, and Davydov have been used:

/119

Equation of state	Molecular hydrogen, H_2		Atomic hydrogen, H		Core	Core density, g/cm^3	H, %	I/MR^2	N
	r/R	MH_2/M	r/R	MH/M	M_{core}/M				
According to Abrikosov	0.45	0.39	0.30	0.12	0.49	12.5	51	0.173	1.0
According to Ramsey	0.66	0.25	0.28	0.39	0.36	11.7	64	0.191	1.8
According to Davydov	0.57	0.42	0.27	0.29	0.29	10.7	71	0.212	2.4

N is the amount of hydrogen in grams per gram of the remaining elements.

Peebles' Model (1964 [IV—99])

/120

The model is calculated on the assumption that Saturn has a deep adiabatic atmosphere (Figure 66). The existence of a central core of heavy elements with a mass equal to ten earth masses is also assumed.

DeMarcus' Model (1958 [IV—80, 81])

The model is constructed on the basis of the interpolated equations for helium and molecular hydrogen derived by DeMarcus and the calculated characteristics of metallic hydrogen (Figure 67). It is shown that hydrogen constitutes no less than 63% of the planet's mass.

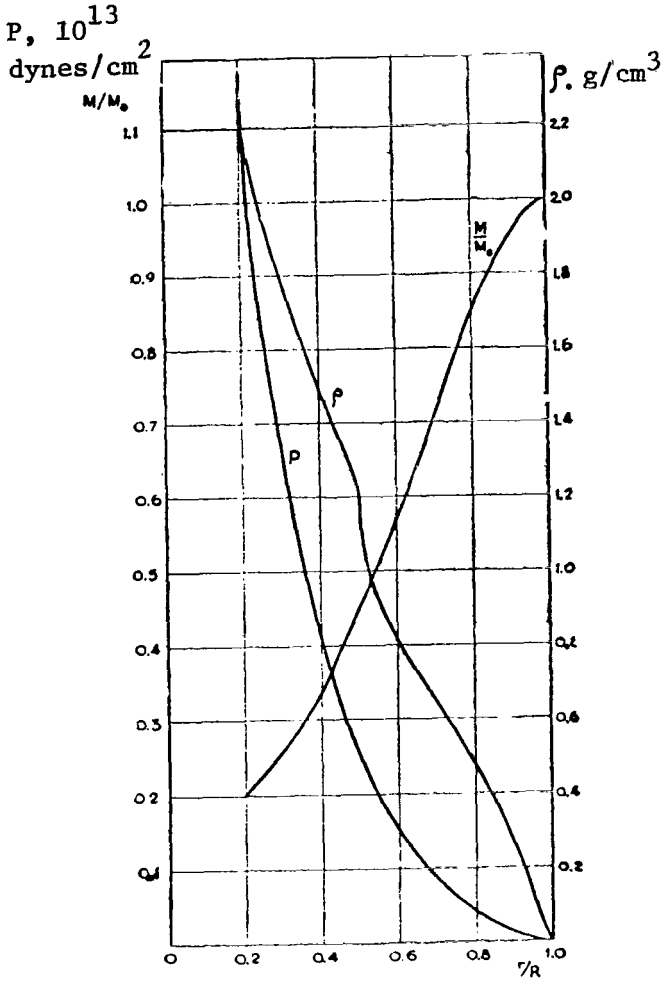


Figure 66. Saturn's internal structure (according to Peebles). The variation of density (ρ), pressure (P), and mass (M) along the planet's radius is shown.

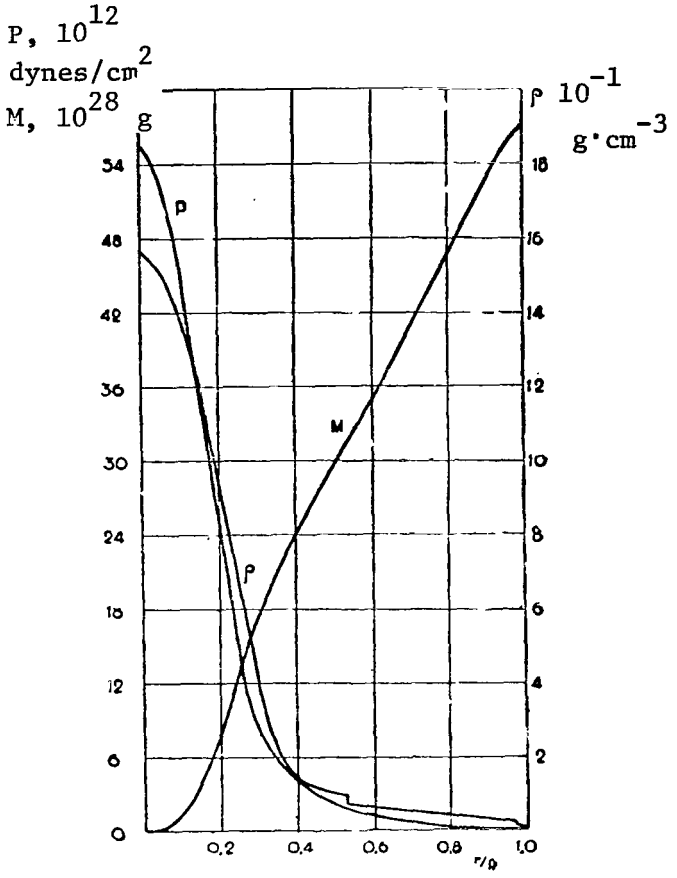


Figure 67. Saturn's internal structure (according to DeMarcus). The notation is the same as on Figure 66.

DISTRIBUTION OF PRESSURE, DENSITY, AND MASS ALONG SATURN'S RADIUS (ACCORDING TO PEEBLES)

r/R	P, 10^{12} dynes/cm^2	ρ, g/cm^3	$M/M_\odot$
0,2	11,5	2,2	0,20
0,3	6,9	1,81	0,26
0,4	4,2	1,49	0,33
0,5	2,5	1,24	0,46
0,55	2,0	0,92	0,51
0,6	1,53	0,81	0,58
0,65	1,16	0,73	0,63
0,7	0,86	0,65	0,70
0,75	0,58	0,56	0,78
0,8	0,37	0,47	0,841
0,85	0,21	0,38	0,900
0,9	0,088	0,27	0,953
0,92	0,055	0,22	0,970
0,94	0,028	0,169	0,983
0,96	$7,9 \cdot 10^{-3}$	0,092	0,995
0,98	$1,44 \cdot 10^{-3}$	0,039	0,9989
0,99	$2,2 \cdot 10^{-4}$	0,0114	0,9998
0,995	$3,4 \cdot 10^{-5}$	$3,0 \cdot 10^{-3}$	0,99998
1,00	$3,0 \cdot 10^{-6}$	$5,5 \cdot 10^{-4}$	1,00

DISTRIBUTION OF DENSITY, MASS, AND PRESSURE ALONG SATURN'S RADIUS (ACCORDING TO DEMARCUS)

r/R	ρ, g/cm^3	M, 10^{27} g	P, 10^{12} dynes/cm^2
1	2	3	4
0,00	15,62	0	55,5
0,05	15,18	1,539	52,7
0,10	13,92	11,696	45,2
0,15	11,93	36,157	34,8
0,20	9,445	75,476	24,0
0,25	6,730	124,33	14,8
0,30	4,155	173,09	8,74
0,35	2,166	211,69	5,49
0,40	1,289	238,64	3,99
0,45	1,163	265,26	3,02
0,50	1,048	295,17	2,24
0,5227	0,999	309,78	1,93
0,5227	0,719	309,78	1,93
0,55	0,678	322,96	1,69
0,60	0,611	348,36	1,32
0,65	0,552	375,80	1,02
0,70	0,498	404,36	0,775
0,75	0,446	434,33	0,568
0,80	0,397	464,55	0,396
0,85	0,347	495,18	0,253

r/R	ρ, g/cm^3	M.10^{27} g	P, 10^{12} dynes/cm^2
1	2	3	4
0,90	0,293	524,45	0,137
0,925	0,268	538,56	0,0894
0,95	0,236	551,86	0,0478
0,970	0,197	561,44	0,0200
0,970	0,185	561,44	0,0200
0,975	0,170	563,46	0,0145
0,980	0,151	565,31	0,00948
0,985	0,125	566,92	0,00518
0,990	0,092	568,20	0,00186
0,995	0,023	568,95	0,00017
1,000	0,00016	569,00	0,000001

According to R. Wildt [I - 4], the lower limit of the pressure and temperature at Saturn's center is $P_c = 1.9 \times 10^6$ atm and $T_c = 2400°$ K.

URANUS

DIMENSIONS

/123

The data on the dimensions refer to the visible surface of the planet's cloud layer.

The angular dimensions at a distance of 1 A.U. are as follows: the average diameter ($\bar{D}''$) is equal to $66''.48 \pm 1''.07$.

LINEAR DIMENSIONS

Average diameter	$\bar{D}$	$48{,}200 \pm 780$ km
Radius	R	24,100 km
Optical oblateness	ε_{opt}	0.056 (1:18)
Volume ($V_E = 1$)	V_U	54

MASS AND GRAVITATIONAL ACCELERATION

Mass	M_V	$8.704 \cdot 10^{28}$ g
	($M_E = 1$)	14.567 ± 0.09
	$\frac{M_\odot}{M_\mathfrak{Y}}$	$22{,}825 \pm 145$
Average density	ρ_U	1.48 ± 0.07 g/cm^2
Gravitational acceleration	g_U	1000 cm/sec^2
	g_U/g_E	1.02
Escape velocity at the surface		22.2 km/sec
Period of axial rotation		10 hr 42 min

INTEGRAL OPTICAL CHARACTERISTICS

Brightness of Uranus

Characteristic	Value
Apparent stellar magnitude	$+5^m.52$
Limits of brightness oscillations	$0^m.29$ with a period of the order of 8 years
	$0^m.26$ with a period of 82 years
Stellar magnitude at a distance of 1 A.U. for the phase angle $\alpha = 0°$	$\bar{V}(1.0) = -7^m.19$
Limits of the oscillations	$-6^m.90$ to $-7^m.27$

/124

COLOR INDEX

Author, year	System	Value
Harris, 1963 [I-6]	U - B	$+0^m.20$
	B - V	$+0^m.56$
	V - R	$-0^m.15$
	R - I	$-0^m.80$
Giclas, 1950-1952 [II-68]	B - V	$+0^m.542$
Teyfel', 1960 [III-41]*		
Apparent color index	550 - 449 nm	$+0^m.42$ to $+0^m.64$
	556 - 440 nm	$+0^m.40$ to $+0^m.46$
True color index	550 - 440 nm	$+0^m.75$ to $+1^m.00$
	556 - 440 nm	$+0^m.77$ to $+1^m.01$

*Spectral measurements of Uranus' color index with account taken of the effect of absorption bands.

ALBEDO

Characteristic	Value	Author, Year
Geometric Albedo		Sinton 1959 [II—101a]
U 3530 Å	0,61	
B 4480 Å	0,67	
V 5540 Å	0,62	
Geometric Albedo		Harris 1963 [I—6]
U 3530 Å	0,530	
B 4480 Å	0,603	
V 5540 Å	0,565	
R 6900 Å	0,325	
Spherical Albedo		Sinton 1959 [II—101a]
U 3530 Å	0,88	
B 4480 Å	0,97	
V 5540 Å	0,89	

MOLECULAR ABSORPTION BANDS IN THE SPECTRUM

Absorption bands of two gases which enter into the composition of the atmosphere of this planet are observed in Uranus' spectrum (Figure 68). These gases are methane (CH_4) and molecular hydrogen (H_2).

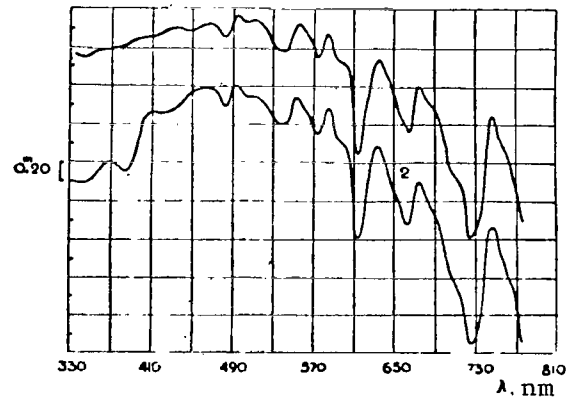


Figure 68. Relative spectral reflectivity (1) and relative energy distribution (2) in Uranus' spectrum (according to Münch and Younkin).

λ, nm	Frequency interpretation	Equivalent width, W, Å	λ, nm	Frequency interpretation	Equivalent width, W, Å
886	$4\nu_3$		649[2]		3.0
874	$9\nu_5$		643	$10\nu_4+\nu_3$	
861	$3\nu_3+\nu_1$		619	$6\nu_3$	115.9[a]
843	$7\nu_4+\nu_3$		614	$13\nu_4$	
816	$5\nu_3-\nu_2$		597	$11\nu_4+\nu_3$	36.0[a]
802	$5\nu_3-\nu_4$		595	$5\nu_3+\nu_1$	
798	$4\nu_3+\nu_4$		584	$7\nu_3-\nu_4$	
788	$10\nu_4$		576	$6\nu_3+\nu_4$	116.2[a]
782	$4\nu_3+\nu_2$		568	$6\nu_3+\nu_2$	
743—759[1]			566	$14\nu_4$	
725	$5\nu_3$		557	$12\nu_4+\nu_3$	
720	$11\nu_4$		543	$7\nu_3$	66.9[a]
702	$4\nu_3+\nu_1$		509	$7\nu_3+\nu_4$	
683	$6\nu_3-\nu_2$		486	$8\nu_3$	
673	$6\nu_3-\nu_4$				
668	$5\nu_3+\nu_4$				
662	$12\nu_4$				
656	$5\nu_3+\nu_2$				

[a] Ya. A. Teyfel' (1960 [III - 41]) determined the equivalent widths of the methane absorption bands.

[1] A group of bands identified with CH_4 by Owen (1967).

[2] A wide band discovered by Spinard (1963 [III - 106]). Owen (1967 [III - 87]) assumes that it is also produced by methane. Its equivalent width has been determined by V. G. Teyfel' and G. A. Kharitonova (1968, 1969 [III - 38, 38a]).

STRUCTURE OF THE CH_4 6800 Å BAND IN URANUS' SPECTRUM ACCORDING TO OWEN (1966 [III—86]) /126

Identification	λ, Å	ν, $см^{-1}$
Q	6824.8	14652.4
R (0)	6819.6	14633.6
R (1)	6815.4	14672.7
R (2)	6810.7	14682.8
R (3)	6804.7	14695.7
R (4)	6798.9	14708.3
R (5)	6793.7	14719.5

This band was first detected and identified with CH_4 by T. Owen (1966 [III - 86]) and later studied by V. G. Teyfel' and G. A. Kharitonova (1969 [III - 38a]). The rotational lines presented in the table are well resolved in it, even at moderate dispersion. However, the identification of the lines is still not sufficiently certain.

Hydrogen

Band, λ, Å	Identification	Equivalent width, mÅ, year of the observations	Note
6435.03	S (0) line of the (4 - 0) H_2 quadrupole band	26 ± 10 1964	Giver and Spinrad, 1966 [III - 63]
"	"	37 ± 12 1965	"
6367.80	S (1) line of the (4 - 0) H_2 quadrupole band	37^{+25}_{-1-} 1964	"
"	"	49 ± 15 1965	"
6420	Wide pressure-induced S (0) dipole line of the (4 - 0) band	3.0 ± 0.5 Å	Giver and Spinrad, 1966 [III - 63]
"	"	4.3 Å	Teyfel' and Kharitonova, 1968 [III - 38, 38a]
8270	Wide pressure-induced S (0) dipole line of the (3 - 0) band		Herzberg, 1952 [III - 64]

CHEMICAL COMPOSITION OF THE OUTER ATMOSPHERE

Estimates of the gas contents in Uranus' atmosphere are very sparse and are still considered as preliminary.

GAS CONTENTS, cm-atm

Author, year	CH_4	H_2
Kuiper, 1947 [I - 20]	2.2×10^5	-
Owen, 1967 [III - 87]	3.5×10^5	-
Herzberg, 1952 [III - 64]	-	4×10^6
McElroy, 1969 [III - 71c]	-	4.8×10^7

RADIATIVE TEMPERATURE

The equilibrium radiative temperature of Uranus is calculated theoretically from the known average albedo of the planet and its distance from the Sun. The solar constant at Uranus' average distance from the Sun (19.191 A.U.) is equal to $S_U = 0.0052$ cal/cm^2·min.

ESTIMATES OF URANUS' EQUILIBRIUM RADIATIVE TEMPERATURE

T, °K	Author, year	Note
49	Kuiper, 1952 [I - 20]	For $A_{vis} = 0.66$
60	Moroz, 1967 [I - 9]	For $A_{int} = 0.50$
47 - 50	Teyfel' and Kharitonova, 1969 [III - 38a]	For the bolometric albedo calculated from the data of Münch and Younkin on Uranus' spectral reflectivity in the λλ 3300 - 7800 Å range (Figure 68).

RADIOMETRIC TEMPERATURE

Low (1966 [III - 70]) found a brightness temperature for the planet of $T_B = 55 \pm 3°$ K from observations of Uranus' infrared radiation in the λλ 17.5 - 25 μ region.

ROTATIONAL TEMPERATURE

The rotational temperature is determined from the relative intensities of lines in the absorption bands of H_2 and CH_4:

T_{rot}, °K	Band	Author, year
124 ± 30	H_2 0.64 μ	Giver and Spinrad 1966 [III - 63]
60 ± 15	CH_4 0.68 μ	Owen, 1966 [III - 86]
60 ± 13 68 ± 15	CH_4 0.68 μ	Teyfel' and Kharitonova

MODEL OF THE OUTER ATMOSPHERE'S STRUCTURE /128

Trafton's Model

L. Trafton [IV - 131] based his calculation of the model for the structure of Uranus' outer atmosphere (Figures 69 - 71) on the same assumptions that were used for Jupiter.

PARAMETERS OF TRAFTON'S MODEL

Parameter	Value
He/H_2	0.00
CH_4/H_2	0.01
Effective temperature	64° K
Temperature of the isothermal stratosphere, T_S	47.5° K
Average optical thickness of the boundary of the convective zone	2.3
Temperature of the upper boundary of the convective zone, T_0	67° K
H_2 content above the cloud layer	53 km-atm
Temperature gradient in the convective zone, Γ_a	1.4° K/km

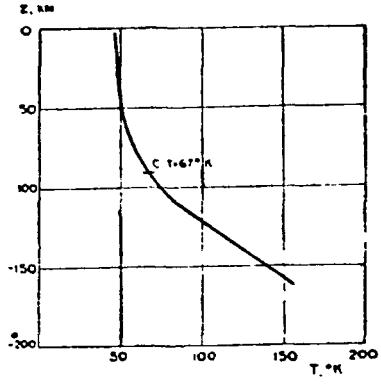


Figure 69. Variation of temperature with altitude in Uranus' atmosphere (according to Trafton). The point labeled C denotes the boundary of the convective zone.

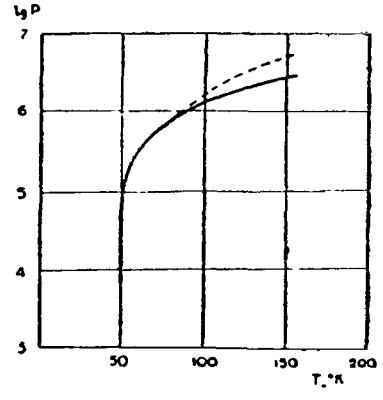


Figure 70. Pressure-temperature dependence in Uranus' atmosphere (according to Trafton). The dashed line takes convection into account.

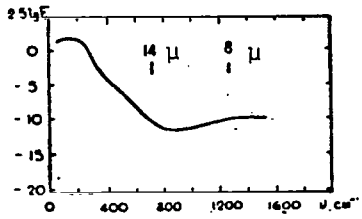


Figure 71. Spectral curve of Uranus' monochromatic thermal emission fluxes (according to Trafton).

RADIO EMISSION

/129

Uranus' radio emission in the centimeter region has been measured. Some of its characteristics are presented below. The nature of this emission is evidently thermal, although there are still little observational data for a definitive conclusion.

URANUS' BRIGHTNESS TEMPERATURE

λ, cm	T_B, °K	Radio emission flux, watts/$m^2 \cdot Hz$	Author, year
1.9	220 ± 35	$(0.48 \pm 0.008) \cdot 10^{-26}$	Kellerman and Pauliny-Toth, 1966 [V - 129]
3.12	158 ± 16	-	Berge, 1967 [V - 40]
3.75	159 ± 16	$(8.75 \pm 0.92) \cdot 10^{-28}$	Klein and Seling, 1966 [V - 130]
11	130 ± 40	$(8.0 \pm 3.5) \cdot 10^{-29}$	Kellerman, 1966, [V - 127]
11.13	180 ± 40	-	Gerard, 1969 [V - 112a]

INTERNAL STRUCTURE

Reynolds' and Summers' Model (1965 [IV—108])

A two-layer model consisting of a stony-ice core and an outer layer of

a mixture of H, He, and Ne (Figure 72).

RADIAL DISTRIBUTION OF PRESSURE AND DENSITY

r/R_0	P, 10^{12} dynes/cm^2	ρ, g/cm^3	r/R_0	P, 10^{12} dynes/cm^2	ρ, g/cm^3
0,00	5,90	4,36	0,55	2,29	3,29
0,05	5,87	4,35	0,60	1,76	3,07
0,10	5,76	4,32	0,65	1,23	2,82
0,15	5,57	4,27	0,70	0,776	2,53
0,20	5,33	4,22	0,773	0,207	1,83
0,25	5,02	4,15	0,773	0,207	0,413
0,30	4,65	4,06	0,80	0,168	0,390
0,35	4,23	3,94	0,85	0,109	0,352
0,40	3,78	3,81	0,90	0,061	0,310
0,45	3,28	3,66	0,95	0,023	0,255
0,50	2,61	3,48	1,00	0,000	0,105

Porter's Model (1961 [IV—102])

The equation of state of solid hydrogen derived by DeMarcus was used. The density function $\rho(r)=\rho_1(r)\cdot\left[1+\gamma\left(1-\frac{r}{R_0}\right)\right]$ was assumed, where $\rho_1(r)$ is the density of ammonia and γ is a constant. The composition is 84% ammonia, 2% hydrogen, and 14% heavier substances (Figure 73).

RADIAL DISTRIBUTION OF DENSITY, MASS, AND PRESSURE /131

r/R_0	ρ, g/cm^3	M/M_0	P, 10^{12} dynes/cm^2
0,05	2,82	0,134	19,5
0,10	2,76	0,136	10,5
0,20	2,72	0,148	5,84
0,30	2,70	0,181	4,07
0,40	2,54	0,244	2,97
0,50	2,32	0,339	2,13
0,60	2,05	0,467	1,43
0,70	1,70	0,620	0,853
0,80	1,29	0,783	0,407
0,90	0,91	0,935	0,097
1,00	0,22	1,000	0,000

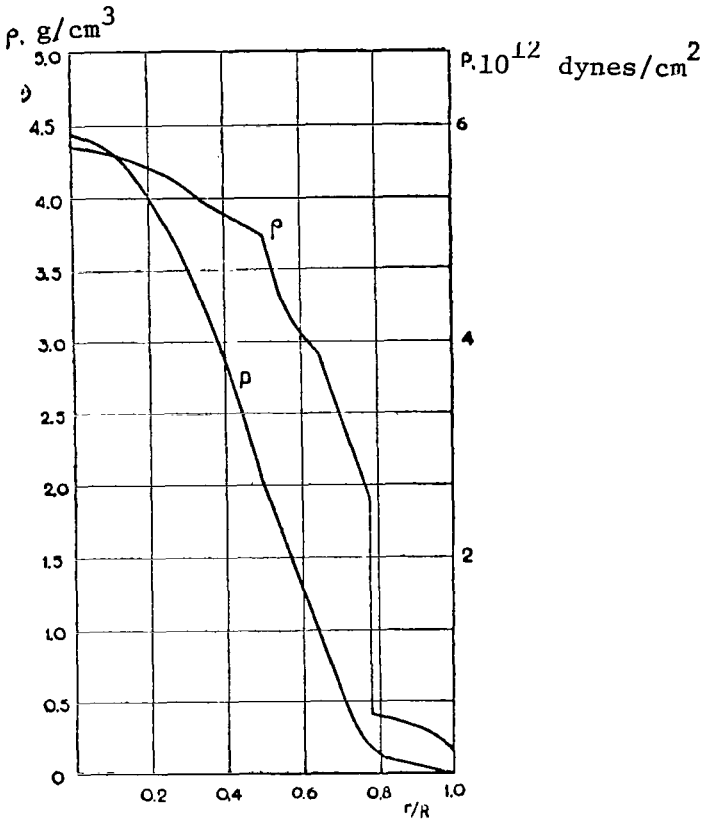


Figure 72. Uranus' internal structure (according to Reynolds and Summers). The variation in density (ρ) and pressure (P) along the planet's radius is shown.

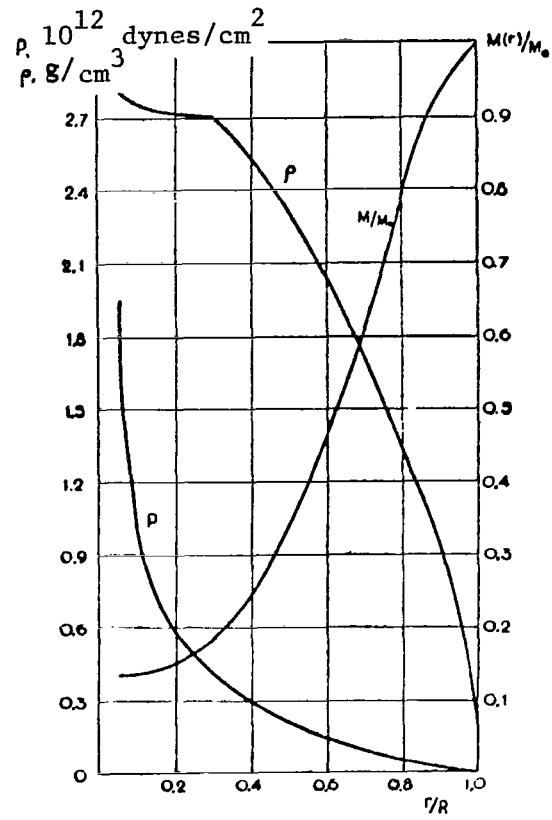


Figure 73. Uranus' internal structure (according to Porter). The variation in density (ρ), pressure (P), and mass (M/M_0) along the planet's radius is shown.

According to K. Wildt [I - 4], the lower limit of pressure and temperature at Uranus' center is $P_c = 1.8 \times 10^6$ atm and $T_c = 11{,}000°$ K.

NEPTUNE

DIMENSIONS

Data on the dimensions refer to the visible surface of the cloud layer.

The angular dimensions at a distance of 1 A.U. are as follows: the average diameter (D") is equal to 63".12 $\pm$ 0".60.

Linear Dimensions

Average diameter	$\bar{D}$	45,750 $\pm$ 500 km
Radius	$\bar{R}$	22,975 km
Optical oblateness	ε_{opt}	0.022 (1:45)
Volume (V_E = 1)	V_N	46
Dynamical oblateness	ε_{dyn}	0.0171 $\pm$ 0.0018

MASS AND GRAVITATIONAL ACCELERATION

Mass	M_N	$1.030 \cdot 10^{29}$ g
	(M_E = 1)	17.246 $\pm$ 0.09
	$\frac{M_\odot}{M_N}$	19,279 $\pm$ 100
Average density	ρ_N	2.06 $\pm$ 0.07 g/km^3
Gravitational acceleration	g_N	1,314 cm/sec^2
	g_N/g_E	1.34
Escape velocity at the surface		2.48 km/sec
Period of axial rotation		15 hr 48 min

INTEGRAL OPTICAL CHARACTERISTICS

Some average optical characteristics which refer to Neptune's entire disk are presented in the following table.

/133

Characteristic	System	Value	Author, year
1	2	3	4
Apparent stellar magnitude	V	+ 7 min, 84	Harris, 1963 [1-6]
Limits of the brightness oscillations	with a period of 21 ± 0.6 years	0 min, 36	Becker, 1933
Stellar magnitude at a distance of 1 A.U. for a phase angle of $\alpha = 0°$	V(1.0)	- 6 min, 87	Harris, 1963
Limits of the oscillations	V(1.0)	- 6 min, 77 to - 7 min, 07	Harris, 1963
Color index	U - B	+ 0 min, 21	Harris, 1963 [1-6]
	B - V	+ 0 min, 41	
	V - R	- 0 min, 33	
	R - I	- 0 min, 80	
Geometric albedo	U	0.5° 5	Harris, 1963 [1-6]
	B	0.624	
	V	0.509	
	R	0.248	
	I	0.091	Sinton, 1959 [II-101a]
	U	0.57	
	B	0.61	
	V	0.49	
Spherical albedo	U	0.82	Sinton, 1959 [II - 101a]
	B	0.88	
	V	0.71	
	U	0.585	Harris, 1963 [1-6]
	B	0.624	
	V	0.509	
	R	0.248	

MOLECULAR ABSORPTION BANDS IN THE SPECTRUM

Very strong methane absorption bands and comparatively weak molecular hydrogen bands are observed in Neptune's spectrum (Figure 74). The bands are strongly overlapped in the infrared region, so that the planet reflects almost no solar radiation.

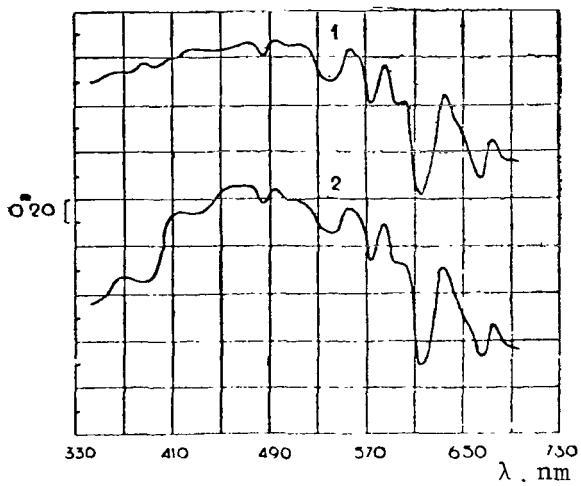


Figure 74. Relative spectral reflectivity (1) with relative energy distribution (2) in Neptune's spectrum (according to Münch and Younkin).

Methane

/134

λ, nm	Frequency interpretation	λ, nm	Frequency interpretation
702	$4\nu_3+\nu_1$	568	$6\nu_3+\nu_2$
683	$6\nu_3-\nu_2$	566	$14\nu_4$
673	$6\nu_3-\nu_4$	557	$12\nu_4+\nu_3$
668	$15\nu_3+\nu_4$	543	$7\nu_5$
662	$2\nu_4$	534	$15\nu_4$
656	$5\nu_3+\nu_2$	523	$13\nu_4+\nu_3$
643	$10\nu_4+\nu_3$	521	$6\nu_3+\nu_1$
619	$6\nu_3$	509	$7\nu_3+\nu_4$
614	$13\nu_4$	504	$7\nu_3+\nu_2$
597	$11\nu_4+\nu_3$	502	$16\nu_4$
595	$5\nu_3+\nu_1$	486	$8\nu_3$
584	$7\nu_3-\nu_4$	459	$8\nu_3+\nu_4$
576	$6\nu_3+\nu_4$	441	$9\nu_3$

Owen (1967, [III - 87]) identified a number of narrow absorption bands in the λλ 7420 - 7590 Å region.

Hydrogen

PRESSURE-INDUCED DIPOLE LINES

λ, Å	Identification
8270	$H_2(3 - 0)$
6420	$H_2(4 - 0)$

CHEMICAL COMPOSITION OF THE OUTER ATMOSPHERE /135

Estimates of the gas contents in Neptune's atmosphere can still be considered as just preliminary.

Gas	Content, cm-atm	Author, year
CH_4	3.7×10^5	Kuiper, 1947 [I-20]
H_2	4×10^6	

RADIATION TEMPERATURE

Neptune's equilibrium radiative temperature has been calculated theoretically from the planet's known average albedo and its distance from the Sun.

The solar constant at Neptune's average distance from the Sun (30.071 A.U.) is $S_N = 0.0021$ cal/cm^2 min. According to Kuiper (1952, [I - 20]), Neptune's equilibrium temperature for $A_{vis} = 0.62$ is equal to 40° K. There are no radiometric measurements of the planet's temperature as of yet.

UPPER ATMOSPHERE

There are almost no data on the structure of Neptune's upper atmosphere. The only information which has been obtained recently is an estimate of the temperature of the planet's atmosphere in the zone of refractive weakening of the brightness of stars. The emergence from behind Neptune's disk of the star BD - 17°4388 (Osawa, Ichimura, and Shimizu, 1968 [II - 89a]) has been observed. J. Kovalevsky and F. Link (1968 [II - 76a]) determined from their analysis of the curve of the star's brightness variation the altitude of a uniform atmosphere as H_0 = 45 km, which gives T = 118° K if hydrogen is the main component of the atmosphere.

MODEL OF THE OUTER ATMOSPHERE'S STRUCTURE

Trafton's Model [IV—131]

Trafton based his calculation of the models for the structure of Neptune's outer atmosphere (Figures 75 - 77) on the same assumptions that were used for Jupiter.

PARAMETERS OF TRAFTON'S MODEL

Parameter	I	II
CH_4/H_2	0.01	0.01
HE/H_2	0	1
Effective temperature, T_e (°K)	40	50
Temperature of an isothermal stratosphere, T_S (°K)	37.4	40.3
Average optical thickness of the depth of the convective zone	2.25	2.7
Temperature at the upper boundary of the convective zone, T_0 (°K)	52	61
H_2 content above the convective zone, km-atm	65	41
Temperature gradient in the convective zone, Γ_a, °K/km	1.3	2.7

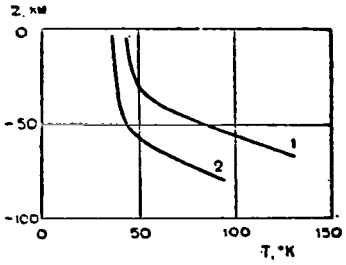


Figure 75. Variation of temperature with altitude in Neptune's atmosphere (according to Trafton). T_e = 50° K; 1 - He:H_2 = 1:1; 2 - He:H_2 = 0:1.

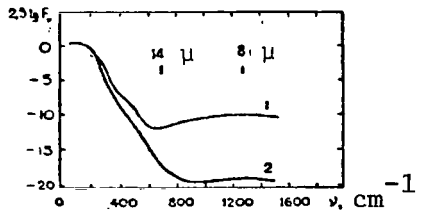


Figure 77. Spectral curves of Neptune's monochromatic thermal emission fluxes (according to Trafton). T_e = 50° K; 1 - He:H_2 = 1:1; 2 - He:H_2 = 0:1.

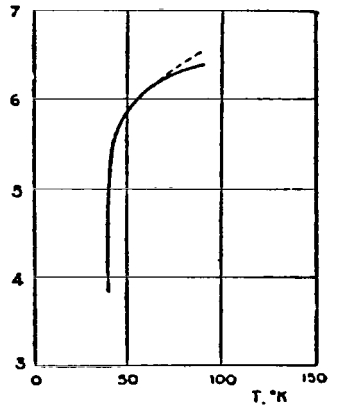


Figure 76. Pressure-temperature dependence in Neptune's atmosphere (according to Trafton) for T_e = 50° K and He:H_2 = 0:1. The dashed line takes convection into account.

RADIO EMISSION

λ, cm	T_B, °K	Flux density, watts/m^2·Hz	Author, year
1.9	180 ± 40	$(0.15 \pm 0.03)\cdot 10^{-26}$	Kellerman and Pauliny-Toth, 1966 [V - 129]
3.12	115 ± 36	—	Berge, 1967 [V - 40]
11.13	<150		Gerard, 1969 [V - 112a]

Porter's Model (1961 [IV—102])

The equation of state of solid hydrogen derived by DeMarcus was used. The density function $\rho(r)=\rho_1(r)\cdot\left[1+\gamma\left(1-\frac{r}{R_0}\right)\right]$, where $\rho_1(r)$ is the density of ammonia and ν is a constant, was assumed. The composition was 74% ammonia and 26% heavier substances (Figure 78). /138

RADIAL DISTRIBUTION OF DENSITY, MASS, AND PRESSURE

r/R_0	ρ, g/cm^3	M/M_0	P, 10^{12} dynes/cm^2
0,05	5,30	0,024	14,8
0,10	5,17	0,026	10,6
0,20	4,90	0,040	8,18
0,30	4,62	0,077	6,81
0,40	4,35	0,144	5,58
0,50	4,08	0,249	4,31
0,60	3,58	0,391	3,04
0,70	2,92	0,558	1,89
0,80	2,14	0,732	0,970
0,90	1,34	0,883	0,352
1,00	0,85	1,000	0,000

Reynolds' and Summers' Model (1965 [IV—108])

A two-layer model consisting of a stony-ice core and an outer layer of a mixture of H, He, and Ne (Figure 79).

RADIAL DISTRIBUTION OF PRESSURE AND DENSITY

r/R	P, 10^{12} dynes/cm^2	ρ, g/cm^3	r/R	P, 10^{12} dynes/cm^2	ρ, g/cm^3
0,00	7,45	4,72	0,55	3,55	3,72
0,05	7,40	4,70	0,60	2,94	3,54
0,10	7,28	4,67	0,65	2,37	3,32
0,15	7,10	4,64	0,70	1,80	3,09
0,20	6,86	4,58	0,80	0,752	2,52
0,25	6,54	4,51	0,85	0,327	2,05
0,30	6,18	4,42	0,883	0,109	1,58
0,35	5,71	4,31	0,883	0,109	0,351
0,40	5,23	4,19	0,90	0,083	0,334
0,45	4,69	4,04	0,95	0,033	0,273
0,50	4,13	3,89	1,00	0,000	0,105

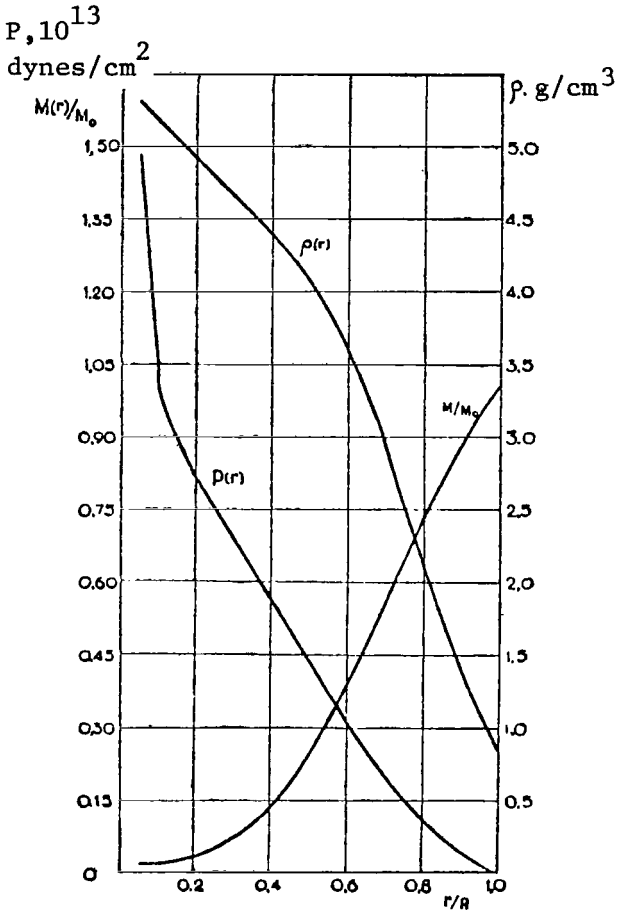


Figure 78. Neptune's internal structure (according to Porter).

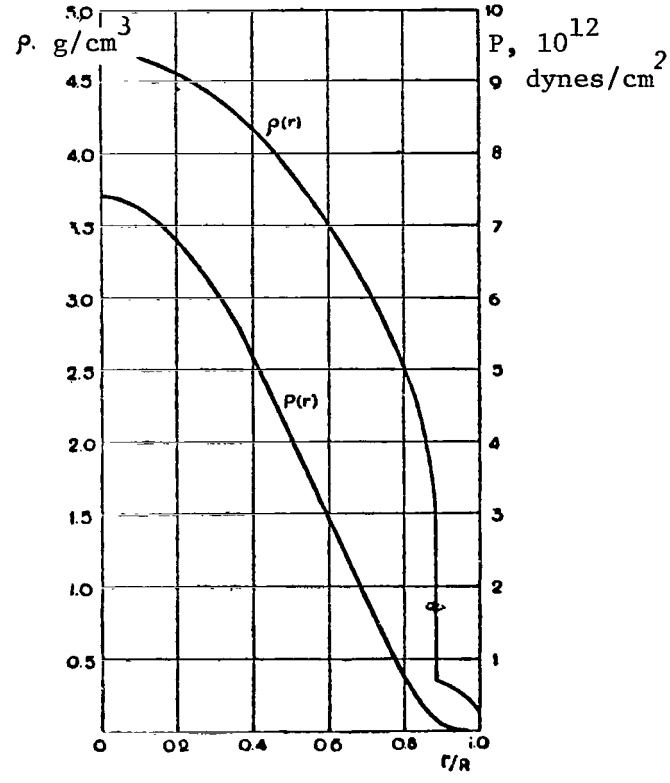


Figure 79. Neptune's internal structure (according to Reynolds and Summers).

According to R. Wildt [I - IV], the lower limit of the pressure and temperature at Neptune's center is $P_c = 3.6 \times 10^6$ atm and $T_c = 12{,}000°$ K.

REFERENCES

This section of the handbook is completely independent and contains a /139
compendium of the majority of original and review articles and also monographs devoted to the problems of the physics of the giant planets which have been published mainly during the last 15 - 20 years. The papers are arranged in alphabetical order by the authors' last names (separately for Russian and foreign languages) in each of the five divisions which comprise this rather broad area of research. Articles containing the results of amateur scientific visual observations, which are published mainly in the Journal of the British Astronomical Association, are not included in the bibliography. In order that a reader who does not have access to the original sources may familiarize himself with the contents of the papers which interest him, the number of an abstract of the article in the abstract journal "Astronomiya" (with an indication of the year and the number of the issue) is presented at the end of the bibliographical description of the majority of articles which have been published since 1952.

I. Reviews and Monographs

1. Barabashov, N. P. Rezul'taty fotometricheskikh issledovaniy Luny i planet na Astronomicheskoy observatorii KhGU (Results of Photometric Investigations of the Moon and the Planets at the Kharkov State University Astronomical Observatory). Kharkov, Kharkov University, 1957, 137 pages.

1a. Bobrov, M.S. Kol'tsa Saturna (Saturn's Rings). Moscow, "Nauka" Press, 1970, 118 pages.

2. Brouwer, D. and G.M. Clemence. The Orbits and Masses of the Planets and Satellites. Collection: Planets and Satellites. Moscow, Foreign Literature Press (IL), 1963, pp. 43-95.

3. Burke, B.F. Observations of Jupiter's Radio Emission. Collection: Planets and Satellites. Moscow, IL, 1963, pp. 416-438.

4. Wildt, R. Internal Structure of the Planets. Collection: Planets and Satellites. Moscow, IL, 1963, pp. 147-191.

5. Gallet, R.M. Observations of Jupiter's Radio Emission. II. Collection: Planets and Satellites. Moscow, IL, pp. 439-468.

6. Harris, D.L. Integral Photometry and Colorimetry of the Planets and Satellites. Collection: Planets and Satellites. Moscow, IL, 1963, pp. 241-305.

7. Dollfus, A. Investigations of the Polarization of the Planets. Collection: Planets and Satellites. Moscow, IL, 1963, pp. 306-325.

8. Kozlovskaya, S.V. The Masses and Radii of the Planets and Satellites. Byull. ITA (Institute of Theoretical Astronomy), Vol. 9, No. 5 (108), pp. 330-376.

9. Moroz, V.I. Fizika planet (Physics of the Planets). Moscow, "Nauka" Press, 1967, 496 pages.

10. Pettit, E. Measurement of the Temperatures of the Planets. Collection: Planets and Satellites. Moscow, IL, 1963, pp. 353-379.

/140

10a. Rubashev, B.M. Problemy solnechnoy aktivnosti (Problems of Solar Activity). Leningrad, "Nauka" Press, 1964, 362 pages.

11. Teyfel', V.G. Planety — giganty (The Giant Planets). Moscow, "Nauka" Press, 1964, 86 pages.

11a. Teyfel', V.G. Atmosfera planety Yupitera (The Atmosphere of the Planet Jupiter). Moscow, "Nauka" Press, 1969, 182 pages.

11b. Sharonov, V.V. Priroda planet (The Nature of the Planets). Moscow, GIFML, 1958, 552 pages.

12. Alexander, A.F. O'D. The Planet Saturn: A History of Observation, Theory and Discovery. London, Faber and Faber, 1962, 474 pages.

13. Alexander, A.F. O'D. The Planet Uranus: A History of Observation, Theory and Discovery. London, Faber and Faber, 1965, 316 pages (1966 1 - 509).

14. Cameron, A.G.W. Physics of the Planets. Space Phys. New York-London-Sydney, John Wiley and Sons, Inc., 1964, pp. 127-165. (1965 6. 51. 481).

15. Eggleston, J.M., D.E. Evans and J.W. Harris. Lunar and Planetary Environments. Towards Deeper Space Penetrat. New York, N.W., Amer. Astronaut Soc., 1964, pp. 7-53 (1966 10. 51. 477).

15a. Goody, R. The Atmospheres of the Major Planets. J. atmosph. sci., Vol. 26, No. 5, Part I, 1969, pp. 997-1001 (1970 9. 51. 274).

16. Herzberg, G. The Atmospheres of the Planets. J. Roy. Astron. Soc. Canada, 1951, Vol. 45, No. 3 (390), pp. 100-123.

17. Hess, S.L. and H.A. Panofsky. The Atmospheres of the Other Planets. Compendium of Meteorology. Boston, American Meteorol Soc., 1951, pp. 391-398.

18. Kiess, C.C. and D.S. Birney. Recent Studies of the Known Physical Characteristics of the Moon and the Planets. Georgetown Observ. Monogr., No. 15, 1960, 18 pages.

19. Kuiper, G.P. Planetary and Satellites Atmospheres. Report on Progress in Physics, Vol. 13, 1950, pp. 247-275.

20. Kuiper, G.P. Planetary Atmospheres and its Origin. Atmospheres of the Earth and Planets, Second edition, 1952, pp. 306-405.

21. Kuiper, G.P. and B.M. Middlehurst (editors). Planets and Satellites. The University of Chicago Press, 1961.

22. Michaux, C.M. Handbook of Physical Properties of the Planet Jupiter. NASA, Washington, 1967.

22a. Mayer, C.H. The Temperatures of the Planets. Scient. Amerc., Vol. 204, No. 5, 1961, pp. 56-65 (1962 1A 499).

23. Peebles, P.J.E. The Big Planets. Internat. Sci. and Technol., No. 35, 1964, pp. 32-38 (1965 5. 51. 442).

24. Peek, B.M. The Planet Jupiter. London, Faber and Faber, 1958, 283 pages.

25. Rasool, S.I. Structure of Planetary Atmospheres. AIAA Journal, Vol. 1, No. 1, 1963, pp. 6-19 (1963 12. 51. 269).

26. Rasool, S.I. Jupiter. "Rosetta Stone" of the Solar System. Astronaut. and Aeronaut., Vol. 6, No. 10, 1968, pp. 24-27.

27. Slipher, E.C. A Photographic Study of the Brighter Planets. Washington, D.C., Nat. Geogr. Soc., 1964, 125 pp.

28. Urey, H.C. The Atmospheres of the Planets. Handbuch der Physik, Vol. 52, 1959, pp. 363-418.

29. Urey, H.C. The Planets. Sci. Space, New York-Toronto-London, McGraw-Hill Book Co., Inc., 1961, pp. 199-217 (1962 7A503).

30. Weil, N.A. Lunar and Planetary Surface Conditions. New York-London, Acad. Press, 1965, 222 pages.

31. Wildt, R., H.T. Smith, E.E. Salpeter and A.G.W. Cameron. The Planet Jupiter. Physics Today, Vol. 16, No. 5, 1963, pp. 19-23.

II. Morphological, Photometric, and Polarization Investigations

1. Aksenov, A.N. Preliminary Results of a Photometric Investigation of the Activity of Jupiter's Atmosphere. Collection: Issledovaniye planety yupitera (Investigation of the Planet Jupiter). Moscow, "Nauka" Press, 1967, pp. 21-26 (1968 7. 51. 507)

2. Aksenov, A.N., Z.N. Grigor'eva, N.V. Priboyeva, Z.G. Romanenko and V.G. Teyfel'. Atmospheric Activity of Jupiter in 1964-1965 on the Basis of Photometric Observational Data. Astron. vestn., Vol. 1, No. 3, 1967, pp. 173-179 (1968 2. 51. 5 4).

3. Aksenov, A.N., Z.N. Grigor'eva, N.V. Priboyeva, Z.G. Romanenko and V.G. Teyfel'. Attempt at Photometric Investigation of Jupiter's Atmospheric Activity in 1964-1965. Tr. astrofiz. Instituta AN Kaz SSR, Vol. 9, 1967, pp. 7-21 (1968 5. 51. 471).

4. Aleksandrov, Yu.V. Determination of the Optical Parameters of the Planets on the Basis of Observations Near Opposition. Vestn. Khar'kovsk. Universiteta, No. 4, seriya. astron., 1965, No. 1, pp. 99-102 (1965 11. 51. 514).

5. Aleksandrov, Yu.V. Results of Surface Photographic Photometry of Jupiter. Vestn. Khar'kovsk. Universiteta, No. 8, seriya astron., 1965, No. 2, pp. 32-37 (1966 10. 51. 470).

6. Aleksandrov, Yu.V. Results of Photographic Photometry of Jupiter. Tr. astrofiz. Instituta AN KazSSR (Transactions of the Kazakh SSR Astrophysical Institute), Vol. 9, 1967, pp. 30-37 (1967 7. 51. 506).

7. Andrianov, N.K. Some Peculiarities of the Red Spot on Jupiter. Uch. zap. Ural'skogo Universiteta, No. 67, 1966 (1967), pp. 96-109) (1968 8. 51. 521).

8. Barabashev, N.P. Photographic Photometry of Jupiter's Disk. Publikatsii astron. Observ. Khar'kovsk. Universiteta, No. 3, 1931, pp. 3-52.

9. Barabashev, N.P. Changes on Jupiter's Surface. Publikatsii astron. Observ. Khar'kovsk. Universiteta, Vol. 7, 1941, pp. 1-20.

10. Barabashev, N.P. Photometry of Jupiter's Bright and Dark Zones. Publikatsii astron. Observ. Khar'kovsk. Universiteta, Vol. 8, 1948, pp. 51-64.

11. Barabashev, N.P. and V.Ye. Semeykin. Monochromatic Photometry of Saturn. Astron. Zh., Vol. 10, No. 4, 1933, pp. 381-390.

12. Barabashev, N.P. and V.Ye. Semeykin. The Atmospheres of Jupiter and Saturn. Astron. Zh., Vol. 11, No. 4, 1934, pp. 301-304.

13. Barabashev, N.P. and A.T. Chekirda. Brightness Distribution on Saturn's Disk and the Brightness of its Rings. Tr. Khar'kovsk. Astron. Observ., Vol. 2, No. 10, 1952, pp. 9-16.

14. Bobrov, M.S. The Value of the Absolute Brightness of Saturn's Ring B. Astron. Zh., Vol. 36, No. 5, 1959, pp. 863-866 (1960 6-5288).

15. Bobrov, M.S. Observations of Star Occultations by Saturn's Rings. Astron. Zh., Vol. 39, No. 4, 1962, pp. 669-677 (1963 2. 51. 510).

16. Bolkvadze, O.R. An Investigation of the Polarization Properties of the Surfaces of Jupiter and Saturn. Tr. Astrofiz. Instituta AN KazSSR, Vol. 9, 1967, pp. 38-41 (1968 5. 51. 480).

16a. Bronshten, V.A., A.N. Sedyakina and Z.A. Strel'tsova. Long-Period Variations in the Width of Jupiter's Belts. Collection: Issledovaniya planety Yupitera (Investigations of the Planet Jupiter). Moscow, "Nauka" Press, 1967, pp. 27-32 (1968 7. 51. 508).

17. Vsekhsvyatskiy, S.K. A Ring of Comets and Meteorites Around Jupiter. Astron. Tsirkulyar, No. 10, 1960, pp. 9-11.

18. Vsekhsvyatskiy, S.K. A Ring of Comets and Meteorites Around Jupiter. Tr. 3-vos yezda Vses. Astron.-Geod. Obshchestva (Transactions of the Third Conference of the All-Union Astronomical-Geodesic Society). Moscow, USSR Academy of Sciences Press, 1962, pp. 119-120 (1962 12A 473).

19. Vsekhsvyatskiy, S.K. Processes in Jupiter's System. Astron. tsirkulyar, No. 317, 1965, pp. 2-4 (1965 10. 51. 387).

20. Vsekhsvyatskiy, S.K. The Nature of the Changes on Jupiter's Surface. Astron. Zh., Vol. 42, No. 3, 1965 (1965 12. 51. 485).

21. Vsekhsvyatskiy, S.K. Main Results of an Analysis of Observations of Jupiter's Surface in 1962-1965. Tr. Astrofiz. Instituta AN KazSSR, Vol. 9, 1967, pp. 22-29 (1968 5. 51. 472). /142

21a. Kartashov, V.F., L.A. Usol'tseva and V.G. Teyfel'. Attempt at Photographic Isodensitometry of Jupiter. Tr. Astrofiz. Instituta AN KazSSR, Vol. 13, 1969, pp. 31-38 (1969 12. 51. 650).

22. Kiladze, R.I. Photographic Observations of Saturn's Rings During the Earth's Passage Through Their Plane. Astron. Tsirkulyar, No. 439, 1967, p. 1 (1968 2. 51. 537).

23. Klyakotko, M.A. Altitude Distribution of Various Features on Jupiter. Astron. Tsirkulyar, No. 111, 1951, pp. 11-12.

24. Kushnir-Ivanovskaya, M.V. and B.M. Rubashev. Dependence of the Variation in the Wind Velocities in Jupiter's Atmosphere on the Long-Term Solar Activity Cycle. Solnechnyye dannyye, No. 5, 1964, pp. 81-85 (1965 2. 51. 546).

25. Lebedinets, V.N. Photometry of Jupiter. Tr. Khar'kovsk. Astron. Observ., Vol. 2, 1952, pp. 33-43.

26. Lebedinets, V.N. Absolute Photographic Photometry of Jupiter and Saturn with Light Filters. Tr. Astron. Observ. Khar'kovsk. Universiteta, Vol. 12, 1957, 167-239 (1958 8-5164).

27. Nikol'skiy, G.M. The Problems of the Nature of the Red Spot. Izv. Astrofiz. Instituta AN KazSSR, Vol. 7, 1958, pp. 58-64 (1960 7-6443).

28. Radlova, L.N. Attempt to Determine the Absolute Photographic Brightness Coefficients of Jupiter's Visible Surface. Uch. Zap. LGU, Vol. 31, 1939, pp. 106-115.

29. Rubashev, B.M. The Appearance of Long-Term Oscillations of the Solar Activity in the Circulation of Jupiter's Atmosphere. Byull. komissii po issled. solntsa (Bulletin of the Commission for Solar Research), No. 8-9, 1953, pp. 47-57 (1954 1-1808).

29a. Sorokina, L.P. Photometric Investigations of Jupiter's Atmospheric Activity in 1965-1966. Tr. Astrofiz. Instituta AN KazSSR, Vol. 13, 1969, pp. 22-30.

30. Teyfel', V.G. Optical Properties and the Structure of Jupiter's Atmosphere. I. Photometric Contrasts, Molecular Absorption, and the Probable Structure of the Dark Equatorial Belt in 1962-1963. Astron. vestn., Vol. 2, No. 4, 1968, pp. 229-238.

31. Teyfel', V.G. The Problem of the Photometric Properties of the Red Spot on Jupiter. Astron. Zh., Vol. 41, No. 3, 1964, pp. 531-538 (1965 1. 51. 578).

32. Fesenkov, V.G. Phenomena Observed on Jupiter. The Origin of the Dark Belts. Izv. Astrofiz. Instituta AN KazSSR, Vol. 1, No. 1-2, 1955, pp. 239-251 (1956 2-1220).

33. Furdylo, V.D. Monochromatic Photometry of Saturn's Rings. Uch. Zap. Khar'kovsk. Universiteta, No. 23, 1941, pp. 53-68.

34. Khodyachikh, M.F. The Structure and Activity of Jupiter's Atmosphere. Vestn. Khar'kovsk. Universiteta, No. 4, 1965, Seriya Astron., No. 1, pp. 86-90 (1965 11. 51. 508).

35. Chekirda, A.T. Brightness Distribution on Jupiter's Disk in Red, Yellow, and Green Light. Tr. Astron. Observ. Khar'kovsk. Universiteta, Vol. 1, No. 9, 1950, pp. 25-28.

36. Sharov, A.S. and Ye. B. Kostyakova. Large Variation in Jupiter's Brightness. Astron. tsirkulyar, No. 295, 1964, pp. 1-3 (1965 1. 51. 576).

37. Sharonov, V.V. Colorimetric Observations of Venus and Jupiter. Astron. tsirkulyar, No. 138, 1953, p. 7 (1953 2-842).

38. Sharonov, V.V. Integral Colorimetry of Jupiter in 1954. Astron. tsirkulyar, No. 152, 1954, pp. 14-15 (1955 4-1566).

39. Sharonov, V.V. Integral Colorimetry of Saturn in 1954. Astron. tsirkulyar, No. 159, 1955, p. 20 (1956 4-2713).

40. Alexander, A.F. O'D. Saturn's Rings-Minor Divisions and Kirkwood's Gaps. J. Brit. Astron. Assoc., Vol. 64, No. 1, 1953-1954, pp. 26-29 /143 (1955 1-281).

41. Baum, R.M. On the Observations of the Reported Dusky Ring Outside the Bright Rings of the Planet Saturn. J. Brit. Astron. Assoc., Vol. 64, No. 5, 1954, pp. 192-196 (1955 2-696).

42. Baum, W.A. and A.D. Code. A Photometric Observation of the Occultation of σ Arietis by Jupiter. Astron. J., Vol. 58, No. 1208, 1953, pp. 108-112 (1953 2-847).

43. Bellier, M., M. Dupré, G. Wlérick, J. Rösch, and J. Arsac. Photometry of Jupiter and Saturn by Means of Pictures Taken with an Electronic Camera. Mem. Soc. roy. sci. Liége, 1963, Vol. 7 No. 1, pp. 522-534 (1964 6. 51. 478).

44. Binder, A. B., D. P. Cruikshank. Evidence for an Atmosphere on Io. Icarus, 1964, Vol. 3, No. 4, pp. 299-305 (1965 8. 51. 572).

45. Binder, A. B., D. P. Cruikshank. Photometric Search for Atmospheres on Europa and Ganimede. Icarus, 1966, Vol. 5, No. 1, pp. 7-9 (1966 8. 51. 544).

45a. Bless, R. C., A. D. Code, D. J. Taylor. Filter Photometry of Saturn in the Spectral Region λλ 2950 - 2450. Astrophys. J., 1968, Vol. 154, No. 3, Part I, pp. 1151-1153 (1969 9. 51. 620).

46. Bogges, A., L. Dunkelman. Ultraviolet Reflectivities of Mars and Jupiter. Astrophys. J., 1959, Vol. 129, No. 1, pp. 236-237 (1959 9-7239).

47. Cailliatte, M. The Densities of Neptune and Pluto. J. observateurs, 1951, Vol. 34, No. 56.

48. Camichel, H. Measurement of Saturn's Rotational Period on the Basis of a Single Spot. Bull. Astron., 1956, Vol. 20, No. 2, pp. 141-144 (1957 2-1431).

49. Camichel, H. Photometric Measurements of Saturn and its Ring. Bull. Astrophys., 1958, Vol. 21, No. 5, 231-242 (1960 7-6444).

50. Chapman, C. R. Dependence of the Prominence of Jupiter's Red Spot on Differential Atmospheric Flow. J. Brit. Astron. Assoc, 1968, Vol. 78, No. 5, pp. 371-374.

51. Chapman, C. R., E. J. Reese. A Test of the Uniformly Rotating Source Hypothesis for the South Equatorial Belt Disturbances on Jupiter. Icarus, 1968, Vol. 9, No. 2, pp. 326-335.

51a. Chapman C. R. Jupiter's Zonal Winds: Variation with Latitude. J. Atmosph. Sci., 1969, Vol. 26, No. 5, Part I, pp. 986-990 (1970 7. 51. 290).

52. Cook, A. F., F. A. Franklin. Optical Properties of Saturn's Rings. I. Transmission. Smithsonian Contribs Astrophys., 1958, Vol. 2, No. 13, pp. 377-383 (1960 2-1502).

53. Cortesi, S. The Formation of Jupiter's Belts. Astronomie, 1960, Vol. 74, February, pp. 63-70 (1960 12-12365).

54. Cragg, T. A. Rotation of Saturn. Publs Astron. Soc. Facif., 1961, Vol. 73, No. 434, pp. 318, 322 (1962 8 A 542).

55. Dollfus, A. Study of the Planets Through the Polarization of their Light. Ann. Astrophys., 1957, Suppl. No. 4, p. 117 (1959 7-5501).

56. Dollfus, A. Motions in Saturn's Atmosphere in 1960. Observations Coordinated by the International Astronomical Union. Icarus, 1963, Vol. 2, No. 2, 109-114 (1964 5. 51. 500).

57. Dollfus, A. A New Satellite of Saturn. C. r. Acad. sci., 1967, Vol. 264, No. 10, pp. B822-B824 (1967 10. 51. 539)

58. Dulk, G. A., J. A. Eddy. A New Search for Visual Aurorae on Jupiter. Astron. J., 1966, Vol. 71, No. 3, p. 160 (1966 9. 51. 512).

59. Falwell, R. L. Spot Cycles of Jupiter and Saturn. Techn. Engng News, 1963, Vol. 45, No. 3, pp. 22-26 (1964 8. 51 442).

60. Feibelman, W. A. Concerning the "D" Ring of Saturn. Nature (Engl.), 1967, Vol. 214, No. 5090, pp. 793-794 (1968 1. 51. 492).

61. Focas, J. H. Preliminary Results Concerning the Atmospheric Activity of Jupiter and Saturn. Mem. Soc. roy. sci. Liége, 1963, Vol. 7, No. 1, pp. 535-544 (1964 4. 51. 448). /144

62. Focas, J. H. Cycles of Atmospheric Activity on Jupiter (Period 1904-63). Trans. Internat. Astron. Union, 1966, XIIB (1964), pp. 207-208.

63. Focas, J. H., C. J. Banos. Photometric Study of the Atmospheric Activity on the Planet Jupiter and Peculiar Activity in its Equatorial Area. Ann. Astrophys., 1964, Vol. 27, No. 1, pp. 36-45 (1964 9. 51. 451).

63a. Focas, J. H. and A. Dollfus. Optical Properties and Thickness of Saturn's Ring Observed Edge-on in 1966. Astron. and Astrophys., 1969, Vol. 2, No. 3, pp. 251-265 (1969 8. 5. 560).

64. Fox, W. E. Jupiter, 1952-53. The Outburst of Activity on the South Equatorial Belt. J. Brit. Astron. Assoc, 1953, Vol. 63, No. 8, p. 345 (1954 5-3560).

65. Franklin, F. A. and A. F. Cook. Optical Properties of Saturn's Rings. II. Two-color Phase Curves of the Two Bright Rings. Astron. J., 1965, Vol. 70, No. 9, pp. 704-720 (1966 7. 51. 492).

65a. Gehrels, T. The Transparency of the Jovian Polar Zones. Icarus, Vol. 10. No. 3, 1969, pp. 410-411 (1970 5. 51. 492).

66. Gehrels, T. The Wavelength Dependence of Polarization of Planetary Atmospheres. Mem. Soc roy. sci. Liége, 1963, Vol. 7, No. 1, p. 116 (1964 1. 51. 495).

66a. Gehrels, T., B. M. Herman, T. Owen. Wavelength Dependence of Polarization. XIV. Atmosphere of Jupiter. Astron. J., 1969, Vol. 74, No. 2, pp. 190-199 (1969 10. 51. 659).

67. Gehrels T. and T. M. Teska. The Wavelength Dependence of Polarization. Communs Lunar and Planetary Lab., 1962, Vol. 1, No. 17-23 (No. 22), pp. 167-177.

68. Giclas, H. L. Photoelectric Magnitudes and Color of Uranus. Astron. J., Vol. 59, No. 3 (1215), 1954, pp. 128-131 (1954 11-5750)

69. Günther, O. The Rotation Light Variation of Neptune. Astron. Nachr., Vol. 282, No. 1, 1955, pp. 1-14 (1956 12-6921).

70. Günther, O. Observations of Neptune's Brightness at the 1953 Opposition. Astron. Nachr., Vol. 282, No. 6, 1955, pp. 247-251 (1956 12-6920).

70a. Hall, J. S. and L. A. Riley. Photoelectric Observations of Mars and Jupiter with a Scanning Polarimeter. Lowell Observ. Bull., No. 145, 1968, pp. 83 - 92 (1969 11. 51. 576).

70b. Hall, J. S. and L. A. Riley. Polarization Measures of Jupiter and Saturn. J. Atmosph. Sci., Vol. 26, No. 5, Part I, 1969, pp. 920-923.

71. Heath, M. B. B. The Longitude of Saturn's Central Meridian. J. Brit. Astron Assoc., Vol. 63, No. 6, 1953, p. 111 (1953 1-384).

72. Holborn, F. M. The Magnitude of Uranus. J. Brit. Astron. Assoc., Vol. 63, No. 6, 1953, pp. 223-224 (1954 2-2298).

73. Holborn, F. M. The Visual Magnitude of Uranus. J. Brit Astron. Assoc., Vol. 65, No. 7, 1955, pp. 284-285 (1956 4-2716).

73a. Ingersoll, A. P. and J. N. Cuzzi. Dynamics of Jupiter's Cloud Bands. J. Atmosph. Sci., Vol. 26, No. 5, Part I, 1969, pp. 981-985 (1970 8. 51. 283).

74. Irvine, W. M., T. Simon, D. H. Menzel, J. Charon, G. Lecomte, P. Griboval and A. T. Joung. Multicolor Photoelectric Photometry of the Brighter Planets. II. Observations from Le Houga Observatory. Astron. J., Vol. 73, No. 4 (1359), 1968, pp. 251-264.

75. Kameny, F. E. Photoelectric Photometry of Uranus and Neptune. Astron. J., Vol. 55, No. 6, 1950, pp. 172.

76. Kimberber, F. The Surface of the Planet Uranus. Sterne, Vol. 41, No. 7-8, 1965, pp. 160-162 (1966 4. 51. 594).

76a. Kovalevsky, J. A New Determination of Neptune's Diameter. C. r. Acad. Sci., Vol. 267, No. 12, 1968, pp. B594-B596 (1969 3. 51. 668).

77. Kuiper, G. P. Titan: a Satellite with an Atmosphere. Astrophys. J., Vol. 100, p. 378.

78. Kuiper, G. P. The Diameter of Neptune. Astrophys J., Vol 110, 1949, pp. 93-94. /145

79. Lenham, A. P. Variations of Rotation Periods and Latitudes of Jovian Features. J. Brit. Astron. Assoc., Vol. 63, No. 4, 1953, pp. 143-145 (1953 2-846).

80. Lenham, A. P. Jupiter Short-Period Variations of Features. J. Brit. Astron. Assoc., Vol. 64, No. 2, 1954, pp. 88-90 (1955 1-279).

81. Lenham, A. P. Jupiter — Variations in the Colour of the Principal Belts 1914 to 1942-1943. J. Brit. Astron. Assoc., Vol. 64, No. 3, 1954, pp. 122-124 (1955 2-695).

82. Lenham, A. P. The Motion of the Red Spot of Jupiter. J. Brit. Astron. Assoc., Vol. 74, No. 5, 1964, pp. 203-205 (1964 11. 51. 454).

83. Link, F. On the Possibility of Luminescence of Jupiter's Satellites. Byull. astron. institutov Chekhoslovakii, Vol. 14, No. 1, 1963, p. 23 (1963 11. 51. 453).

84. Löbering, W. The Great Red Spot on Jupiter. Astron. Nachr., Vol. 281, No. 5-6, 1954, pp. 265-266 (1955 10-4446).

85. Lyot, B. Polarization of the Planet Jupiter. C. r. Acad. sci., Vol. 179, 1924, pp. 671-673.

86. Malsch, W. The Brightness of Uranus at Opposition in 1954. Sterne, Vol. 30, No. 7-8, 1954, p. 143 (1955 6-2452).

87. Malsch, W. The Brightness of Uranus at Opposition in 1953. Sterne, Vol. 29, No. 7-8, 1953, p. 165 (1954 2-2299).

87a. Marin, M. Photographic Photometry of Saturn. J. Observateurs, Vol. 51, No. 3, 1968, pp. 179-191 (1969 1. 51. 513).

88. Mitchell, R. I. Photoelectric Observations of Uranus and Neptune. Publs Astron. Soc. Pacif., Vol. 69, No. 411, 1957, pp. 565-568 (1958 10-6596).

89. Nielsen, A. V. The Visual Magnitude of Uranus. J. Brit. Astron. Assoc., Vol. 65, No. 7, 1955, pp. 283-284 (1956 4-2715).

89a. Osawa K., K. Ichimura and M. Shimizu. Occultation of BD-17° 4388 by Neptune on 7 April 1968. II. Observationaat Okayama Station and the Scale Height of Nepture. Tokyo Astron. Bull. Tokyo Astron. Observ., No. 184, 1968, pp. 2183-2187 (1939 3. 51. 666).

90. Peek, B. M. Correlation Between the Varying Rotation Periods of Jupiter's Great Red Spot and North Equatorial Current. Monthly Notices Roy Astron. Soc., Vol. 128, No. 6, 1964, pp. 509-512 (1965 8. 51. 536).

91. Polesny, B. The Periodic Variations in the Period of Rotation of Jupiter's Red Spot. Sterne, Vol. 42, No. 9-12, 1966, pp. 222-225 (1967 10. 51. 494).

92. Pokorny, Z. Changes in the Period of Rotation of Jupiter's Red Spot. Sterne, Vol. 43, No. 7-8, 1967, pp. 171-172 (1968 7. 51. 518)

93. Reese, E. J., H. G. Solberg. Recent Measures of the Latitude and Longitude of Jupiter's Red Spot. Icarus, Vol. 5, No. 3, 1966, pp. 266-273 (1967 2. 51. 536).

94. Richardson, R. S. Photometry of the Disk of Uranus. Publs Astron. Soc. Pacif., Vol. 67, No. 398, 1955, pp. 355-356 (1956 4-2714).

95. Robinson, J. H. A Note on the Magnitude of Uranus, 1955. J. Brit. Astron Assoc, Vol. 66, No. 1, 1956, pp. 24-25 (1956 10-5734).

96. Robinson, L. J. Observations of the Rotation of Saturn. Publs. Astron. Soc. Pacif., Vol. 73, No. 434, 1961, pp. 347-349 (1962 8A 543).

97. Rogèrio de Freitas Mourao Ronaldo. A Search for Periodicity in the Thickness of Jupiter's N. E. B. Mèm. Soc. roy. sci. Liége, Vol. 7, No. 1, 1963, pp. 463-467 (1964 5. 51. 497).

98. Roth, G. D. The Unusual Rotation of a Dark Object in Saturn's North Equatorial Belt. Astron. Nachr., Vol. 281, No. 2, 1953, pp. 89-92 (1953 3-1321). /146

99. Schoenberg, E. and W. D. Heintz. Brightness Variations of Jupiter's Dark Belts. Astron. Nachr., Vol. 282, No. 2, 1955, pp. 85-88 (1955 9-3935).

100. Shapiro, R. The Distribution and Velocities of Bright and Dark Spots on Jupiter's Surface in 1928. The Study of Planetary Atmospheres, Final Report, Lovell Obs., 1952, pp. 116-126.

101. Shapiro, R. A Planetary-Atmospheric Response to Solar Activity. J. Meteorol., Vol. 10, No. 5, 1953, pp. 350-355 (1954 5-3558).

101a. Sinton, W. Lowell Observ. Bull., Vol. 4, No. 95, 1959, p. 93.

102. Smith, B. A. and C. W. Tombaugh. Observations of the Red Spot on Jupiter. Publs.Astron. Soc. Pacif., Vol. 75, No. 446, 1963, pp. 436-440 (1964 11. 61. 455).

103. Spangenberg, W. W. Investigations of the Planet Uranus' Appearance in Small Telescopes. Astron. Nachr., Vol. 287, No. 1-2, 1963, pp. 23-32 (1963 12. 51. 481).

104. Spangenberg, W. W. Shadow Phenomena of Saturn's Ring. Sterne, Vol. 43, No. 9-10, 1967, pp. 196-200 (1968 7. 51. 520).

105. Steavenson, W. H. The Satellites of Uranus. J. Brit. Astron. Assoc., Vol. 74, No. 2, 1964, pp. 54-59 (1964 10. 51. 491).

106. Struve, O. The Atmospheres of Jupiter and Saturn. Sky and Telescope, Vol. 13, No. 10, 1954, pp. 336-338 (1955 6-2450).

107. Sudbury, P. V. Isodensitometry of Jupiter. Icarus, Vol. 4, No. 5-6, 1965, pp. 547-548 (1966 7. 51. 490).

108. Talley, R. L., H. G. Horak. The Phase Variations of Uranus. Astrophys. J., Vol. 123, No. 1, 1956, pp. 176-178 (1956 11-6394).

109. Vsekhsvyatskiy, S. K. The Ring of Comets and Meteorites around Jupiter. Mèm. Soc. roy. sci. Liége, Vol. 7, No. 1, 1963, pp. 468-470 (1964 6. 51. 477).

110. Wegner, G. Color Variations of the Great Planets. Publs Astron. Soc. Pacif., Vol. 74, No. 441, 1962, pp. 413-414.

111. Wlerick, G., J. Rosch, M. F. Dupre, and Mlle. M. Bellier. Electronic Photography of the Planets and its Photometric Applications. Photo-Electronic Image Devices. New York-London, Academic Press, 1962, pp. 371-380 (1965 6. 51. 498).

III. Spectral and Radiometric Investigations

1. Avramchuk, V. V. Ultraviolet Absorption in Various Zones of Jupiter. Collection: Fizika Luny i planet (Physics of the Moon and the Planets). Kiev, Nauk. dumka, 1966, pp. 82-90 (1967 2. 51. 534).

1a. Avramchuk, V. V. Spectrophotometry of the Ammonia 6441 Å and 6478 Å Absorption Bands on Jupiter's Disk. Astron. tsirkulyar, No. 483, 1968, pp. 5-7 (1969 4. 51. 575).

2. Avramchuk, V. V. Results of Spectrophotometry of the Methane 6190 Å Absorption Band on Jupiter's Disk. Astron. tsirkulyar, No. 449, 1967, pp. 1-3 (1968 5. 51. 478).

2a. Avramchuk, V. V. The Distribution of Methane Absorption in the 6190 Å Band across Jupiter's Disk. Astrometriya i astrofizika, Kiev, Nauk. dumka, No. 1, 1968, pp. 126-160 (1969 5. 51. 520).

3. Avramchuk, V. V. Spectrophotometry of the Methane 6190 Å Absorption Band on Saturn's Disk. Astron. tsirkulyar, No. 452, 1967, pp. 1-3 (1968 8. 51. 526).

3a. Avramchuk, V. V. Distribution of Methane Absorption in the 6190 Å Band across Saturn's Disk in 1966. Astrometriya i astrofizika, Kiev, Nauk. dumka, No. 1, 1968, pp. 161-164 (1969 5. 51. 523).

4. Avramchuk, V. V. Determination of the Optical Properties of Jupiter's Atmosphere. Astron. tsirkulyar, No. 484, 1968, pp. 4-6. /147

4a. Aksenov, A. N. Investigation of the Ammonia Absorption in the NH_3 6450 Å Band in Jupiter's Atmosphere. Tr. Astrofizich. instituta, Vol. 13, 1969, pp. 13-15 (1969 12, 51. 647).

5. Barabashov, N. P. and A. T. Chekirda. Photographic Spectrophotometry of Venus, Mars, Jupiter, and Saturn. Tr. Astron. observ. Khar'kovsk. universiteta, Vol. 1, No. 9, 1950, pp. 19-23.

6. Galkin, L. S. Some Properties of Jupiter's Atmosphere. I. Izv. Krymsk. astrofiz. observ., Vol. 32, 1964, pp. 11-13 (1965 2. 51. 545).

7. Galkin, L. S. Some Properties of Jupiter's Atmosphere. III. Izv. Krymsk. astrofiz. observ., Vol. 35, 1966, pp. 248-252 (1967 3. 51. 582).

7a. Galkin, L. S. Some Properties of Jupiter's Atmosphere. III. Izv. Krymsk. astrofiz. observ., Vol. 39, 1969, pp. 232-235 (1969 9. 51. 617).

8. Galkin, L. S. Some Properties of Jupiter's Atmosphere on the Basis of Spectrophotometric Observations. Tr. astrofiz. instituta AN KazSSR, Vol. 9, 1967, pp. 42-46 (1968 5. 51. 473).

8a. Galkin, L. S., L. A. Bugayenko, O. I. Bugayenko, and A. V. Morozhenko. The Spectrum of Uranus in the 4800-7500 Å Region. Astron. tsirkulyar, No. 533, 1969, pp. 1-2 (1970 6. 51. 539).

9. Glushneva, I. N. Dependence of the Albedoes of Venus and Jupiter on Wavelength in the Ultraviolet Region of the Spectrum. Astron. zh., Vol. 41, No. 4, 1964, pp. 720-723 (1965 2. 51. 539).

9a. Grigor'eva, Z. N. and N. V. Priboyeva. Spectral and Color Contrasts on Jupiter's Disk. Tr. Astrofiz. instituta AN KazSSR, Vol. 13, 1969, pp. 16-21 (1969 12. 51. 648).

10. Yeropkin, D. I. The Spectrum of Jupiter's Polar and Equatorial Zones. Dokl. AN SSSR, No. 4, 1933, pp. 143-145.

11. Kalinyak. A. A. Data on the Spectra of the Galilean Satellites of Jupiter. Astron. zh., Vol. 42, No. 5, 1965, pp. 1067-1069 (1966 3. 51. 628).

12. Klyakotko, M. A. The Structure of Jupiter's Atmosphere. Byull. Vses. astronomo-geodez. obshchestva, No. 13, 1953, pp. 21-23 (1953 1-378).

13. Kartashov, V. F. Ultraviolet Absorption in Spectra of Jupiter. Tr. Astrofiz. instituta AN KazSSR, Vol. 9, 1967, pp. 47-50 (1968 5. 51. 474).

13a. Kozyrev, N. A. Water Vapor in Saturn's Ring and its Thermal Effect on the Planet's Surface. Izv. Gl. astron. observ. AN SSSR, No. 184, 1968, pp. 99-107 (1969, 6. 51. 567).

14. Krinov, Ye. L. Attempt to Study the Spectral Reflectivity of Mars and Jupiter. Astron. zh., Vol. 12, 1935, pp. 557-563.

15. Moroz, V. I. Infrared Spectra of Jupiter and Saturn in the 0.9 to 2.5 Micron Region. Astron. zh., Vol. 38, No. 6, 1961, pp. 1080-1084 (1962 4A 519).

16. Moroz, V. I. Infrared Spectra of Io and Ganymede in the 0.7 to 2.5 Micron Region. Astron. tsirkulyar, No. 297, 1964, pp. 1-2 (1965 3. 51. 450).

17. Moroz, V. I. Spectra of Jupiter and Saturn in the 1 - 2.5 Micron Region. Astron. zh., Vol. 43, No. 3, 1966, pp. 579-592 (1966 10. 51. 474).

17a. Moroz, V. I. Attempt at Infrared Spectrophotometry of Satellites: the Moon and the Galilean Satellites of Jupiter. Astron. zh., Vol. 42, No. 6, 1965, pp. 1287-1295 (1966 7. 51. 494).

18. Moroz, V. I., N. V. Vasil'chenko, L. B. Danilyants, and S. A. Kaufman. Attempt at Astronomical Observations in the 8 - 14 Micron Region with a Photoconductive Cell Cooled by Liquid Helium. Astron. zh., Vol. 45, No. 1, 1968, pp. 189-194 (1968 7. 51. 163).

18a. Moroz, V. I., V. D. Davydov, and V. S. Zhegulev. Photometric and Spectral Observations of the Planets in the 8 - 14 Micro' Region. Astron. zh., Vol. 46, No. 1, 1969, pp. 136-146 (1969 8. 51. 543).

19. Priboyeva, N. V. The Continuous Spectra of Jupiter's Satellites. Tr. Astrofiz. instituta AN KazSSR, Vol. 9, 1967, pp. 94-97 (1968 5. 51. 488).

20. Teyfel', V. G. Intensity Distribution across Jupiter's Disk in the Methane Absorption Bands. Astron. tsirkulyar, No. 201, 1959, pp. 3-4 (1960 9-9089). /148

21. Teyfel', V. G. Intensity Distribution across Jupiter's Disk in the Methane Absorption Bands. Izv. Komissii po fiz. planet, No. 1, 1959, 93-104 (1961 1A 430).

22. Teyfel', V. G. Intensity of the CH_4 6190 Å Band in Jupiter's Spectrum in 1959. Astron. tsirkulyar, No. 210, 1960, pp. 11-14 (1961 2A 482).

23. Teyfel', V. G. Spectrophotometry of Jupiter's Equatorial Region in 1959. Astron. tsirkulyar, No. 215, 1960, pp. 7-9 (1962 7A 516).

24. Teyfel', V. G. Photometry of the Continuous Spectrum of Jupiter's Equatorial Zone. Izv. Astrofiz. instituta AN KazSSR, Vol. 13, 1962, pp. 54-61 (1963 5. 51. 492).

25. Teyfel', V. G. The Altitude of the Upper Boundary of the Red Spot on Jupiter. Astron. tsirkulyar, No. 232, 1962, pp. 8-11 (1963 10. 51. 471).

26. Teyfel', V. G. The Problem of the Ultraviolet Absorption in Jupiter's Continuous Spectrum. Izv. AN KazSSR, seriya fiz.-matem. nauk, Vol. 16, No. 1. Astrofizika, pp. 74-77 (1964 2. 51. 535).

27. Teyfel', V. G. The Latitude Distribution of Methane Absorption on Jupiter's Disk. Astron. tsirkulyar, No. 296, 1964, pp. 1-4 (1965 4. 51. 399).

28. Teyfel', V. G. Spectrophotometry of the Methane Absorption Bands on Jupiter's Disk in the Near-Infrared Region (0.7 - 1.0 μ). Astron. zh., Vol. 43, No. 1, 1966, pp. 154-156 (1966 8. 51. 509).

29. Teyfel', V. G. CH_4 Absorption in Saturn's Equatorial Zone on the Basis of Photoelectric Measurements. Astron. tsirkulyar, No. 421, 1967, pp. 1-3 (1968 2. 51. 536).

30. Teyfel', V. G. Spectrophotometry of the Red Spot on Jupiter. Tr. Astrofiz. instituta AN KazSSR, Vol. 9, 1967, pp. 57-58 (1968 5. 51. 476).

31. Teyfel', V. G. Distribution of the Molecular Absorption of Methane on Jupiter's Disk in the Near-Infrared Region (0.7 - 1.0 μ). Tr. Astrofiz. instituta AN KazSSR, Vol. 9, 1967, pp. 63-82 (1968 5. 51. 477).

32. Teyfel', V. G. A Comparison of the Distribution of Absorption in the CH_4 6190 Å Band on the Disks of Jupiter and Saturn. Tr. Astrofiz. instituta AN KazSSR, Vol. 9, 1967, pp. 59-62 (1968 5. 51. 479).

33. Teyfel', V. G. The Intensity of the Methane and Ammonia Absorption in the Red Spot on Jupiter. Astron. tsirkulyar, No. 446, 1967, pp. 3-5 (1968 8. 51. 520).

33a. Teyfel', V. G. The Continuous Spectrum and Molecular Absorption in the Red Spot on Jupiter. Tr. Astrofiz. instituta AN KazSSR, Vol. 13, 1969, pp. 3-12 (1969 12. 51. 646).

34. Teyfel', V. G. Molecular Absorption of Light in Jupiter's Atmosphere and the Structure of the Surface of the Planet's Cloud Layer. Collection: Issledovaniye planety Yupitera (Investigation of the Planet Jupiter). Moscow, "Nauka" Press, 1967, pp. 3-20.

35. Teyfel'. V. G. and N. V. Proboyeva. The Intensity of Methane Absorption in the CH_4 6190 Å Band on Jupiter's Disk. Izv. AN KazSSR, seriya fiz.-matem. nauk, Vol. 16, No. 1. Astrofizika, 1964, pp. 61-73 (1964 6. 51. 472).

36. Teyfel', V. G. and Ya. A. Teyfel'. Attempt at Spectrophotometry of Saturn. Astron. tsirkulyar, No. 188, 1958, pp. 14-16 (1959 9-7244).

37. Teyfel', V. G. and Ya. A. Teyfel'. Attempt at Spectrophotometry of Saturn. Tr. Sektora astrobotan. AN KazSSR, Vol. 7, 1959, pp. 64-68, (1961 2A 484).

38. Teyfel', V. G. and G. A. Kharitonova. Estimates of the Rotational Temperature and Pressure in Uranus' Atmosphere. Astron. tsirkulyar, No. 484, 1968, pp. 6-8.

38a. Teyfel', V. G. and G. A. Kharitonova. The Rotational Temperature and Upper Limit to the Pressure in Uranus' Atmosphere. Astron. zh., Vol. 46, No. 5, 1969, pp. 1104-1114 (1970 4. 51. 291). /149

39. Teyfel', Ya. A. The CH_4 6190 Å Absorption Band in Saturn's Spectrum. Astron. tsirkulyar, No. 189, 1958, pp. 9-10 (1959 9-7245).

40. Teyfel', Ya. A. The Equivalent Widths of the CH_4 Absorption Bands in Uranus' Spectrum. Astron. tsirkulyar, No. 195, 1958, p. 9 (1959 8-6461).

41. Teyfel', Ya. A. Some Results of Spectrophotometry of Uranus Tr. Sektora astrobotan. AN KazSSR, Vol. 8, 1960, pp. 76-80 (1962 2A 471).

42. Khodyachikh. M. F. Absolute Photometry of Jupiter's Continuous Spectrum. Vestn. Khar'kovsk. universiteta, seriya astron., Issue 3, No. 28, 1967, pp. 102-110 (1968 8. 51. 517).

42a. Khodyachikh, M. F. Some Peculiarities of Jupiter's Atmosphere. Vestn. Khar'kovsk. universiteta, seriya astron., Issue 4, No. 34, pp. 71-78 (1969 10. 51. 661).

43. Shayn, G. A. Intensity Distribution in the Spectrum of Saturn and Its Ring. Tsirkulyar Gl. astron. observ. v Pulkove, Vol. 13, 1935, 9-16.

44. Shnyrev, G. D., V. N. Grechushnikov, and V. I. Moroz. Investigation of Saturn's Infrared Spectrum by the Fourier Transformation Method. Astron. tsirkulyar, No. 302, 1964, pp. 1-4 (1965 7. 51. 507).

45. Adel, A. Jupiter and Saturn: NH_3 Bands Spectra. Phys. Rev., Vol. 48 1935, p. 103.

46. Adel, A. and V. M. Slipher. Jupiter, Saturn, Uranus and Neptune; CH_4 Atmospheric Content. Phys. Rev., Vol. 46, 1934, p. 47.

47. Adel, A. and V. M. Slipher. On the Identification of the Methane Bands in the Solar Spectra of the Major Planets. Phys. Rev., Vol. 46, 1934, pp. 240-241.

47a. Anderson, R. C., J. G. Pipes, A. L. Broadfoot and L. Wallace. Spectra of Venus and Jupiter from 1800 to 3200 Å. J. Atmosph. Sci., Vol. 26, No. 5, Part 1, 1969, pp. 874-888.

47b. Aumann, H. H., C. M. Gillespie and F. J. Low. The Internal Powers and Effective Temperatures of Jupiter and Saturn. Astrophys. J., Vol. 157, No. 1, Part 2, 1969, pp. 69-72 (1970 3. 51. 297).

48. Beckman, J. E. The Pressure at the Cloud Top and the Abundance of Hydrogen in the Atmosphere of Jupiter. Astrophys. J., Vol. 149, No. 2, Part 1, 1967, pp. 453-454 (1968 3. 51. 507).

49. Beckman, J. E. The Measurement of Abundances in Planetary Atmospheres Using an Image Intensifier and a Solar Spectrograph. Planet. and Space Sci., Vol. 15, No. 7, 1967, pp. 1211-1218 (1968 4. 51. 548).

49a. Belton, M. J. S. An Estimate of the Abundance and the Rotational Temperature of CH_4 on Jupiter, Astrophys. J., Vol. 157, No. 1, Part I, 1969, pp. 469-472.

50. Binder, A. B. and D. P. Cruikshank. On the Spectra of the Galilean Satellites of Jupiter. Astrophys. J., Vol. 144, No. 3, 1966, pp. 1240-1241 (1966 12. 51. 476).

51. Bruce, J. T. Princeton on Jupiter. Princeton Engr., Vol. 28, No. 3, 1967, pp. 8-9, 16 (1968 9. 51. 468).

52. Clarke, D. and J. F. Grainger. The Profile of H_β in the Spectrum of Jupiter. Planet. and Space Sci., Vol 13, No. 11, 1965, p. 1164 (1966 5. 51. 503).

53. Cruikshank, D. P. and A. B. Binder. The Infrared Spectrum of Jupiter, 0.95 - 1.60 microns, with Laboratory Calibrations. Communs Lunar and Planetary Lab., No. 103, 1968.

53a. Cruikshank, D. P. and A. B. Binder. Minor Constituents in the Atmosphere of Jupiter. Astrophys. and Space Sci., Vol. 3, No. 3., 1969 pp. 347-356.

54. Danielson, R. E. The Infrared Spectrum of Jupiter. Astrophys. J., Vol. 143, No. 3, 1966, pp. 949-960 (1966 10. 51. 471).

55. Danielson, R. E. The Infra-red Spectrum of Jupiter obtained by Stratoscope II. Trans. Internat. Astron. Union, XIIB (1964), 1966, pp. 212-213. /150

56. Danielson, R. E., W. K. Rose, M. Schwarzschild and N. J. Woolf. New Infrared Observations with Stratoscope II. Astron. J., Vol. 69, No. 8, 1964, p. 539 (1965, 7. 51. 189).

56a. Emerson, J. P., J. A. Eddy and G. A. Dulk. Hydrogen Abundance in Jupiter's Atmosphere. Icarus, Vol. 11, No. 3, 1969, pp. 413-416.

57. Evans, D. C., A. Boggess and R. Scolnik. The Reflectivity of Venus and Jupiter in the Middle Ultraviolet. Astron. J., Vol. 70, No. 5, 1965, p. 321 (1965 12. 51. 474).

57a. Farmer, C. B. An Estimate of Line Width and Pressure from High Resolution Spectrum of Jupiter at 11 000 Å. J. Atmosph. Sci., Nol. 26, No. 5, Part I, 1969, pp. 860-861.

58. Fehrenback, Ch., and P. Guerin. An Anomaly in the Behavior of the NH_3 Bands in the spectrum of the Planet Jupiter. C. r. Acad. sci., Vol. 258, No. 5, 1964, pp. 1403-1405 (1964 8. 51. 441).

58a. Fink, U. and M. J. S. Belton. Collision-narrowed curves of growth for H_2 Applied to New Photoelectric Observations of Jupiter. J. Atmosph. Sci., Vol. 25, No. 5, Part I, 1969, pp. 952-962 (1970 9. 51. 283).

59. Foltz, J. V. and D. H. Rank. Intensity of the 4 - 0 Quadrupole Band of Molecular Hydrogen. Astrophys. J., Vol. 138, No. 4, 1963, pp. 1319-1321 (1964 6. 51. 254).

60. Frederick, L. W. On the Infrared Reflectivity of Saturn's Rings. Publs Astron. Soc. Pacif., Vol. 75, No. 446, 1963, p. 414 (1965 2. 51. 548).

60a. Gillett * F. C., F. J. Low, and W. A. Stein. The 2.8 - 14-micron Spectrum of Jupiter. Astrophys. J., Vol. 157, No. 2, Part I, 1969, pp. 925-934 (1970 5. 51. 287).

61. Giver, L. P. Line Inclinations in Equatorial Spectra of Jupiter and Saturn. Astrophys. J., Vol. 139, No. 2, 1964, pp. 727-733 (1965 1. 51. 583).

62. Giver, L. P. High-Dispersion Spectrograms of Jupiter and Saturn. Publs Astron Soc. Pacif., Vol. 77, No. 455, 1965, pp. 128-129 (1965 10. 51. 388).

62a. Giver, L. P., R. W. Boese, and J. H. Miller. Laboratory Studies of the Visible NH_3 Bands with Applications to Jupiter. J. Atmosph. Sci., Vol. 26, No. 5, Part I, 1969, pp. 941-942 (1970 8. 51. 282).

63. Giver, L. P. and H. Spinrad. Molecular Hydrogen Features in the Spectra of Saturn and Uranus. Icarus, Vol. 5, No. 6, 1966, pp. 586-589 (1967 10. 51. 500).

64. Herzberg, G. Spectroscopic Evidence of Molecular Hydrogen in the Atmospheres of Uranus and Neptune. Astrophys. J., Vol. 115, No. 3, 1952, pp. 337-340.

65. Hess, S. L. Variations in the Atmospheric Absorption over the Disks of Jupiter and Saturn. Astrophys. J., Vol. 118, No. 1, 1953, pp. 515-160 (1954 2-2296).

*Translator's Note: Incorrectly given as Gillet in foreign text.

65a. Hunter, J. H. H_α Auroral Activity on Jupiter. Nature (Engl.), Vol. 223, No. 5204, 1969, pp. 388-389 (1970 2. 51. 281).

66. Jelley, J. V. A further search for H_α aurorae on Jupiter. Trans. Internat. Astron. Union, XIIB (1964), 1966, pp. 217-219.

67. Jelley, J. V. and A. D. Petford. A Preliminary Search for Short-Period H(α) Activity from the Planet Jupiter, During the Apparation to 1960. Mèm. Soc. roy. sci. Liége, Vol. 7, No. 1, 1963, pp. 471-480 (1964 6. 51. 474).

67a. Jenkins, E. B. Far-Ultraviolet Spectroscopy of Jupiter. Icarus, Vol. 10, No. 3, 1969, pp. 379-385 (1970 4. 51. 287).

68. Kiess, C. C., C. H. Corliss, and H. K. Kiess. High-Dispersion Spectra of Jupiter. Astrophys. J., Vol. 132, No. 1, 1960, pp. 221-231 (1962 1A 512).

69. Low, F. J. Infrared Brightness Temperature of Saturn. Astron. J., Vol. 69, No. 8, 1964, pp. 550-551 (1965 5. 51. 441). /151

70. Low, F. J. Observations of Venus, Jupiter and Saturn at λ 20 μ. Astron. J., Vol. 71, No. 6, 1966, p. 391 (1967 4. 51. 539).

71. Low, F. J. The Infrared Brightness Temperature of Uranus. Astrophys. J., Vol. 146, No. 1, 1966, pp. 326-328 (1967 7. 51. 581).

71a. Margolis, J. S. and K. Fox. Studies of Methane Absorption in the Jovian Atmosphere. I. Rotational Temperature from the $3\nu_3$ Bands. Astrophys. J., Vol. 157, No. 2, Part I, 1969, pp. 935-943 (1970 3. 51. 288).

71b. Margolis, J. S. and K. Fox. Extension of Calculations of Rotational Temperature and Abundance of Methane in the Jovian Atmosphere. J. Atmosph. Sci., Vol. 26, No. 5, Part I, 1969 pp. 862-864 (1970. 9. 51. 277).

71c. McElroy, M. B. Atmospheric Composition of the Jovian Planets. J. Atmosph. Sci., Vol. 26, No. 5, Part I, 1969, pp. 798-812 (1970 5. 51. 272).

72. Mertz, L. and I. Coleman. Infrared Spectrum of Saturn's Ring. Astron. J., Vol. 71, No. 8, 1966, pp. 747-748 (1967 5. 51. 498).

72a. Moos, H. W., W. G. Fastie, and M. Bottema. Rocket Measurement of Ultraviolet Spectra of Venus and Jupiter between 1200 and 1800 Å. Astrophys. J., Vol. 155, No. 3, Part I, 1969, pp. 887-897 (1969 11. 51. 562).

73. Moroz, V. I. Recent Observations of Infrared Spectra of Planets (Venus 1 - 4 μ, Mars 1 - 4 μ, Jupiter 1 - 1.6 μ). Mèm. Soc. roy. sci. Liége, Vol. 9, 1964, pp. 408-419 (1965 1. 51. 562).

73a. Moroz, V. I. and D. P. Cruikshank. Distribution of Ammonia on Jupiter. J. Atmosph. Sci, Vol. 26, No. 5, Part I, 1969, pp. 865-869 (1970 9. 51. 279).

74. Münch, G. and H. Spinrad. On the Spectrum of Saturn. Mèm. Soc. roy. sci. Liége, Vol. 7, No. 1, 1963, pp. 541-542 (1964 1. 51. 510).

75. Münch, G. and R. L. Younkin. Molecular Absorptions and Color Distributions over Jupiter's Disk. Astron. J., Vol. 69, No. 8, 1964, p. 553 (1965 5. 51. 435).

76. Münch, G. and R. L. Younkin. Color and Molecular Absorption over the Disks of Jupiter and Saturn. Trans. Internat. Astron. Union, XIIB (1964), 1966, p. 214.

77. Murray, B. C., J. A. Westphal, and R. L. Wildey. The Eclipse Cooling of Ganymede. Astrophys. J., Vol. 141, No. 4, 1965, pp. 1590-1592 (1966 3. 51. 629).

78. Murray, B. C.,and R. L. Wildey. Stellar and Planetary Observations at 10 Micorns. Astrophys. J., Vol. 137, No. 2, 1963, pp. 692-693 (1964 1. 51. 219).

79. Murray, B. C., R. L. Wildey, and J. A. Westphal. Observations of Jupiter and the Galilean Satellites at 10 Microns. Astrophys. J., Vol. 139, No. 3, 1964, pp. 986-993 (1965 1. 51. 582).

80. Nishida, M. and J. Jugaku. The Stratospheric Rotation of Jupiter in November 1963. J. Atmosph. Sci., Vol. 21, No. 5, 1964, pp. 568-569 (1965 5. 51. 436).

81. Owen, T. C. Comparisons of Laboratory and Planetary Spectra I. The Spectrum of Jupiter from 9000 - 10100 Å. Communs Lunar and Planetary Lab., Vol. 2, No. 24, 1963, pp. 24-29, 65-69 (1964 8. 51. 440).

82. Owen, T. C. Comparisons of Laboratory and Planetary Spectra I. The Spectrum of Jupiter from 9000 - 10100 Å. Publs Astron. Soc. Pacif., Vol 75, No. 445, 1963, pp. 314-322 (1965. 1. 51. 579).

83. Owen, T. C. Comparisons of Laboratory and Planetary Spectra. II. The Spectrum of Jupiter from 9700 to 11200 Å. Astrophys. J., Vol. 141, No. 2, 1965, pp. 444-456 (1966 1. 51. 506).

84. Owen, T. Saturn's Ring and the Satellites of Jupiter: Interpretations of Infrared Spectra. Science, Vol. 149, No. 3687, 1965, pp. 974-975 (1966 4. 51. 636).

85. Owen, T. Comparisons of Laboratory and Planetary Spectra. III. The Spectrum of Jupiter from 7750 to 8800 Å. Astrophys. J., Vol. 142, No. 2, 1965, pp. 782-786 (1966 5. 51. 502). /152

86. Owen, T. An Identification of the 6800 Å Methane Band in the Spectrum of Uranus and a Determination of Atmospheric Temperature. Astrophys. J., Vol. 146, No. 2, 1966, pp. 611-613 (1967 9. 51. 540).

87. Owen, T. Comparisons of Laboratory and Planetary Spectra. IV. The Identification of the 7500 Å Bands in the Spectra of Uranus and Neptune. Icarus, Vol. 6, No. 1, 1967, pp. 108-113 (1967 10. 51, 501).

88. Owen, T. On the Abundance of Ethane in the Atmospheres of Jupiter and Saturn. Icarus, Vol. 6, No. 1, 1967, pp. 138-140 (1967 10. 51. 496).

88a. Owen, T. The Spectra of Jupiter and Saturn in the Photographic Infrared. Icarus, Vol. 10, No. 3, 1969, pp. 355-364 (1970 5. 51. 291).

89. Owen, T. and H. P. Mason. The Abundance of Hydrogen in the Atmosphere of Jupiter. Astrophys. J., 1968.

89a. Owen, T. and H. P. Mason. New Studies of Jupiter's Atmosphere. J. Atmosph. Sci., Vol. 26, No. 5, Part I, 1969, 870-873 (1970 9. 51. 280).

90. Owen, T., E. H. Richardson, and H. Spinrad. A New Ammonia Band in the Jovian Spectrum. Astrophys. J., Vol. 139, No. 4, 1964, pp. 1374-1377 (1965 1. 51. 580).

91. Owen, T. C. and D. O. Staley. A Possible Jovian Analogy to the Terrestrial Equatorial Stratospheric Wind Reversal. J. Atmosph. Sci., Vol. 20, No. 4, 1963, pp. 347-350.

92. Owen, T. and J. H. Woodman. On the Atmospheric Temperature of Jupiter Derived from the $3\nu_3$ Methane Band. Astrophys. J., Vol. 154, No. 1, Part 2, 1968, pp. 21-23.

93. Plummer, W. T. Hot Shadow on Jupiter. Discussion on the Paper: "On the Infrared Opacity of Jupiter's Outer Atmosphere" by R. L. Wildey - Author's Reply. Science, Vol. 153, No. 3742, 1966, pp. 1418-1419 (1967 6. 51. 264).

94. Robertson, J. . IR Scan of Jupiter, Saturn for Water Carbondioxide, set. Electron News, Vol. 8, No. 389, 1963, p. 54 (1964 6. 51. 479).

95. Sargent, W. L. W. and R. M. Catchpole. Inclination of the Jovian Ammonia Lines in 1962. Observatory, Vol. 84, No. 941, 1964 (1965 8. 51. 535).

95a. Schwitters, M. T. A Search for Jovian Limb Aurorae. Icarus, Vol. 9, No. 3, 1968, pp. 570-573 (1969 10. 51. 664).

96. Sinton, W. Infra-red Spectra of Jupiter and Saturn. Trans. Internat. Astron. Union, XIIB (1964), 1966, pp. 213-214.

96a. Sinton, W. M. and J. Strong. Radiometric Observations of Venus. Astrophysics. J., Vol. 131, No. 2, 1960, pp. 470-490 (1961 10A 446).

97. Slipher, V. M. On the Spectra of Neptune and Uranus. Lovell Observ. Bull., No. 13, 1904, pp. 87-90.

98. Slipher, V. M. The Spectra of Major Planets. Lovell Observ. Bull., Vol. 1, No. 42, 1909, pp. 231-238.

99. Slipher, V. M. Spectrographic Studies of the Planets. Monthly Notices Roy. Astron. Soc., Vol. 93, No. 9, 1933, pp. 657-689.

100. Spinrad, H. On the Continuous Spectrum of Venus and Jupiter. Publs Astron. Soc. Pacif, Vol. 74, No. 437, 1962, p. 311 (1963 1. 51. 478).

101. Spinrad, H. The Anomalous Inclination of the Jovian Ammonia Lines. Astrophys. J., Vol. 136, No. 1, 1962, p. 311 (1963 1. 51. 478).

102. Spinrad, H. Pressure - Induced Dipole Lines of Molecular Hydrogen in the Spectra of Uranus and Neptune. Astrophys. J., Vol. 138, No. 4, 1963, pp. 1242-1245 (1964 7. 51. 222).

103. Spinrad, H. Spectroscopic Research on the Major Planets. Appl. Optics, Vol. 3, No. 2, 1964, pp. 181-186 (1964 8. 51. 428).

104. Spinrad, H. and L. P. Giver. Jupiter and Saturn: Planetary Line Inclinations. Publs Astron. Soc. Pacif., Vol. 78, No. 461, 1966, pp. 175-177 (1966 10. 51.,475). /153

105. Spinrad, H., G. Münch, and L. Trafton. Recent Spectroscopic Investigations of Jupiter and Saturn. Astron. J., Vol. 67, No. 9, 1962, p. 587 (1963 9. 51. 449).

106. Spinrad, H. and L. M. Trafton. High Dispersion Spectra of the Outer Planets. I. Jupiter in the Visual and Red. Icarus, Vol. 2, No. 1, 1963, pp. 19-28 (1964 5. 51. 496).

107. Stecher, T. P. An Observation of Jupiter in the Ultraviolet. Ann. Astrophys., Vol. 28, No. 4, 1965, pp. 788-790 (1966 3. 51. 383).

108. Stecher, T. P. The Reflectivity of Jupiter in the Ultraviolet. Astrophys. J., Vol. 142, No. 3, 1965, pp. 1186-1190 (1966 7. 51. 489).

109. Tanaka, W. H_2 - Abundance in Jupiter's Atmosphere. Publs Astron. Soc. Japan, Vol. 18, No. 4, 1966, pp. 339-344 (1967 11. 51. 467).

110. Tanaka, W. H_2 - Abundance in Saturn's Atmosphere. Proc. Japan Acad., Vol. 43, No. 10, 1967, pp. 971-973 (1968 11. 51. 609).

111. Taylor, D. J. Spectrophotometry of Jupiter's 3400 - 10000 A Spectrum and a Bolometric Albedo for Jupiter. Icarus, Vol. 4, No. 4, 1965, pp. 362-373 (1966 3. 51. 582).

112. Teifel, V. G. Some Data on the Intensity of Methane Absorption in the Atmosphere of Jupiter. Mém. Soc. roy. sci. Liège, Vol. 7, No. 1, 1963, pp. 589-592 (1964 4. 51. 445).

113. Teifel, V. G. Some Considerations on the Optical Properties of the Upper Atmosphere of Jupiter. Trans. Internat. Astron. Union, XIIB (1964), 1966, pp. 209-212.

113a. Teifel, V. G. Molecular Absorption and the Possible Structure of the Cloud Layers of Jupiter and Saturn. J. Atmosph. Sci Vol. 26, No. 5, Part I, 1969, pp. 854-859 (1970 9. 51. 285).

114. Walker, M. F. and S. Hayes. Image Tube Observations of the $3\nu_3$ Band of CH_4 in the Spectrum of Jupiter. Publs Astron. Soc. Pacif., Vol. 79, No. 470, 1967, pp. 464-472 (1968 8. 51, 518).

114a. Westphal, J. A. Observation of Localized 5-micron Radiation from Jupiter. Astrophys. J., Vol. 157, No. 1, Part 2, 1969, pp. 63-64 (1970 3. 51. 289).

115. Wildey. R. L. Hot Shadows on Jupiter. Science, Vol. 147, No. 3661, 1965, pp. 1035-1036 (1965 10. 51. 386).

116. Wildey, R. L. On the Interpretation of Thermal Emission Maps of Jupiter. J. Geophys. Res., Vol. 70, No. 15, 1965, pp. 3796-3797 (1966 2. 51. 533).

117. Wildey, R. L. Mapping the Brightness - Temperature Distribution of Jupiter at 10 μ. Astron. J., Vol. 70, No. 9, 1965, pp. 696-697 (1966 6. 51. 543).

118. Wildey, R. L. Thermal Contrast of Eclipse Shadows and Band Structure During the 1965 Apparition of Jupiter. Astrophys. J., Vol. 144, No. 3, 1966, pp. 1241-1244 (1967 1. 51. 445).

118a. Wildey, R. L. Structure of the Jovian Disk in the ν_2-Band of Ammonia at 100 000 Å. Astrophys. J., Vol. 154, No. 2, Part I, 1968, pp. 761-770 (1969 12. 51. 651).

119. Wildey, R. L., B. C. Murray, and J. A. Westphal. Thermal Infrared Emission of Jovian Disk. J. Geophys. Res., Vol. 70, No. 15, 1965, pp. 3711-3719 (1966 2. 51. 532).

120. Wildt, R. Absorption Spectra and the Atmosphere of the Giant Planets. Nachr. Ges. Akad. Wiss. Göttingen, No. 1, 1932, pp. 87-96.

121. Wildt, R. The Infrared Spectrum of the Planet Saturn. Götting. Nachr., No. 4, 1932, pp. 356-359.

122. Younkin, R. L. and G. Münch. Spectral Energy Distributions of the Major Planets. Mém. Soc. roy. sci. Liège, Vol. 7, No. 1, 1963, pp. 125-136 (1964 1. 51. 507).

123. Younkin, R. L. and G. Münch. Wavelength dependence of the Band Structures of Jupiter and Saturn. Astron. J., Vol. 69, No. 8, 1964, p. 565 (1965 5. 51. 440). /154

124. Younkin, R. L. and G. Münch. Visible and Near - Infrared Spectrophotometry of Saturn's Rings: Astron. J., Vol. 71, No. 3, 1966, p. 188 (1966 9. 51. 515).

125. Zabriskie, F. R. Hydrogen Content of Jupiter's Atmosphere. Astron. J., Vol. 67, No. 3, 1962, pp. 168-170 (1962 12A 471).

IV. Theoretical Investigations and Laboratory Experiments

1. Abrikosov, A. A. The Equation of State of Hydrogen at High Pressures. Astron. zh., Vol. 31, No. 2, 1954, pp. 112-123 (1955 3-1024).

2. Abrikosov, A. A. The Internal Structure of Hydrogen Planets. Vopr. kosmogonii, Vol. 3, 1954, pp. 11-19 (1955 7-2950).

3. Bobrov, M. S. Physical Interpretation of the Phase Curve of Saturn's Rings. Astron. zh., Vol. 17, No. 6, 1940, pp. 1-8.

4. Bobrov, M. S. The Structure of Saturn's Rings. I. The Degree of Roughness and Albedo of the Particles of Ring B. Astron. zh., Vol. 29, No. 3, 1952, pp. 334-340.

5. Bobrov, M. S. The Structure of Saturn's Rings. II. Estimate of the Bulk Density of Ring B. Astron. zh., Vol. 31, No. 1, 1954, pp. 41-50 (1954 8-4573).

6. Bobrov, M. S. The Problem of Thickness of Saturn's Rings. Astron. zh., Vol. 33, No. 3, 1956, pp. 161-172 (1959 7-5511).

7. Bobrov, M. S. The Structure of Saturn's Rings. III. An Estimate of Particle Sizes and the Mass of the Rings. Astron. zh., Vol. 33, No. 6. 1956, pp. 904-911 (1959 9-7243).

8. Bobrov, M. S. Derivation of a Theoretical Phase Function of Saturn's Rings and Its Comparison With Observations. Astron. zh., Vol. 36, No. 1, 1959, pp. 129-133 (1959 11-9131).

9. Bobrov, M. S. Theoretical Phase Curves of the Shadow Effect on Saturn's Rings. I. Derivation of the Equations. Astron. zh., Vol. 37, No. 2, 1960, pp. 306-316 (1961 7A 412).

10. Bobrov, M. S. Generalization of the Theory of the Shadow Effect on Saturn's Rings to the Case of Particles of Non-Identical Sizes. Astron. zh., Vol. 38, No. 4, 1961, pp. 669-680 (1962 2A 470).

11. Bobrov, M. S. Present State of the Problem of the Structure and Order of Magnitude of the Thickness of Saturn's Rings. Tr. Astrofiz. instituta AN KazSSR, Vol. 9, 1967, pp. 83-93 (1968 5. 51. 481).

12. Zheleznyakov, V. V. The Configuration of Saturn's Magnetic Field. Collection: Vopr. kosmogonii (Problems of Cosmogony), Moscow, "Nauka" Press, Vol. 10, 1964, pp. 61-69 (1965 1. 51. 313).

13. Zheleznyakov, V. V. The Configuration of Saturn's Magnetic Field. Astron. zh., Vol. 41, No. 5, 1964, pp. 955-962 (1965 4. 51. 206).

14. Zheleznyakov, V. V. Generation of Jupiter's Radio Emission. Astron. zh., Vol. 42, No. 4, 1965, pp. 798-809 (1966 1. 51. 507).

15. Zlotnik, E. Ya. The Effect of the Rings on Saturn's Exosphere and Magnetic Field. Astron. zh., Vol. 44, No. 3, 1967, pp. 581-592 (1967 12. 51. 504).

16. Ivanov, B. S. The Problem of Determining a Planet's Rate of Rotation and the Inclination of its Axis from the Radiation Received at its Satellite. Kosmicheskiye issledovaniya, Vol. 4, No. 5, 1966, pp. 709-712 (1967 3. 51. 422).

17. L'vov, N. The Figure and Internal Structure of the Four Outer Giant Planets. I. Astron. zh., Vol. 9, No. 1-2, 1932, pp. 68-76; II. Astron. zh., Vol. 10, No. 2, 1933, pp. 141-154.

18. Kozlovskaya, S. V. The Internal Structure and Chemical Composition of the Giant Planets. Dokl. AN SSSR, Vol. 108, No. 3, 1956, pp. 409-413 (1957 7-5660). /155

19. Korchak. A. A. Synchrotron Radiation of Charged Particles in a Dipole Magnetic Field. Astron. zh., Vol. 40, No. 6, 1963, pp. 994-1006 (1964 8. 51. 310).

20. Lebedinskiy. A. I. The Hydrogen Content in the Giant Planets. Vopr. kosmogonii (Problems of Cosmogony), Vol. 7, 1960, pp. 50-54.

21. Naumov, A. P. and I. P. Khizhnyakov. Jupiter's Thermal Emission. Astron. zh., Vol. 42, No. 3, 1965, pp. 629-638 (1965 12. 51. 345).

22. Nicolet, M. The Effect of Short-Wavelength Ultraviolet Solar Radiation on the Atmosphere of the Earth and the Other Planets. Collection: Spektry zvezd v dalekom ul'trafiolete (Stellar Spectra in the Far Ultraviolet). Moscow, Mir, 1964, pp. 162-195.

23. Potanov, I. N. The Three Systems which Characterize Jupiter's Rotation. Collection: Issled. planety Yupitera (Investigation of the Planet Jupiter). Moscow, "Nauka" Press, 1967, pp. 88-90 (1968 7. 51. 516).

24. Pochtarev, V. I. The Magnetic Field of the Planets from Data Acquired in the Investigation of the Magnetic Properties of Meteorites. Geomagnetizm i aeronomiya, Vol. 7, No. 4, 1967, pp. 745-747 (1968 3. 51. 492).

24a. Ruskol, Ye. L. The Chemical Composition and Internal Structure of the Planet Jupiter. Kosmicheskiye issledovaniya, Vol. 7, No. 6, 1969, pp. 857-870.

25. Teyfel', V. G. The Size of the Temperature Gradient in the Supra-Cloud Layer of Jupiter's Atmosphere. Astron. tsirkulyar, No. 298, 1964, pp. 1-3 (1965 1. 51. 577).

25a. Teyfel', V. G. The Optical Properties and Structure of Jupiter's Atmosphere. II. The Effect of Multiple Scattering in the Cloud Layer on the Shape of Planetary Absorption Lines. Astron. vestnik, Vol. 3, No. 2, 1969, pp. 85-95.

26. Fesenkov, V. G. Jupiter's Internal Structure. Astron. zh., No. 3-4, 1924.

27. Fesenkov, V. G. and A. G. Masevich. The Problem of the Structure and Chemical Composition of the Large Planets. Astron. zh., Vol. 28, No. 5, 1951, pp. 317-338.

28. Shabanskiy, V. P. The Generation of Electric Fields in the Magnetosphere and the Acceleration of Particles of the Polar Aurorae. Geomagnetizm i aeronomiya, Vol. 7, No. 2, 1967, pp. 243-247 (1967 8. 62. 271).

29. Adamcik, J. A. On the Formation of Nitrogen Oxides in Planetary Atmospheres. Publs.Astron. Soc. Pacif., Vol. 74, No. 439, 1962, pp. 328-329 (1963 6. 51. 268).

30. Adel, A. and V. M. Slipher. The Constitution of the Atmospheres of the Giant Planets. Phys. Rev., Vol. 46, 1934, pp. 902-906.

31. Alfvén, H. On the Structure of the Saturnian Rings. Icarus, Vol. 8, No. 1, 1968, pp. 75-81 (1968 10. 51. 555).

32. Bardwell, J. and G. L. Herzberg. Laboratory Experiments on the Detectability of Silane (SiH_4) and Methyl Deuteride (CH_3D) in the Atmospheres of the Outer Planets. Astrophys. J., Vol. 117, No. 3, 1953, pp. 462-465.

33. Bartha L. Generation of the Earth's Magnetism. Fiz. szemle, Vol. 10, No. 5, 1960, p. 150 (1961 12A 567).

34. Beckman, J. E. A Cloud Model for the Upper Atmosphere of Jupiter. Publs Astron. Soc. Pacif., Vol. 79, No. 470, 1967, pp. 427-428 (1968 8. 51. 519).

35. Bobrov, M. S. Optics and Geometry of the Matter of Saturn's Rings. Mém. Soc. roy. sci. Liège, Vol. 7, No. 1, 1963, pp. 516-521 (1964 6. 51. 481).

36. Brandt, J. C. Hydrogen and Helium Resonance Radiation from the Planets. Mém. Soc. roy. sci. Liége., Vol. 7, No. 1, 1963, pp. 137-142 (1964 1. 51. 497).

37. Brandt, J. C. A Note on Rayleigh and Raman Scattered Lyman-α-Radiation from Jupiter and Saturn. Planet. and Space Sci., Vol. 11, No. 6, 1963, pp. 725-726 (1964 3. 51. 255). /156

38. Briggs, M. H. The Colouring Matter and Radio Emissions of Jupiter. Observatory, Vol. 80, No. 917, 1960, pp. 159-161 (1961 10A 460).

39. Bullen, K. E. Planetary Interiors. J. Astron. Soc. Victoria, Vol. 19, No. 5, 1966, pp. 74-76 (1967 11. 51. 232).

40. Bullen, K. E. On the Internal Constitutions of the Planets. Proc. Astron. Soc. Austral., Vol. 1, No. 1, 1967, pp. 2-3 (1968 5. 51. 251).

41. Cadle, R. D. The Photochemistry of the Upper Atmosphere of Jupiter. J. Atmosph. Sci., Vol. 19, No. 4, 1962, pp. 281-285 (1963 1. 51. 477).

42. Colombo, G. and F. Franklin. On the Saturn Ring. Atti 11 Conv. Soc. Astron. ital., Padova, 1967, S. 1., s. a., pp. 74-78.

42a. Colombo, G. and F. Franklin. A Theory of the Dynamical Structure of the Saturn Ring Supported by Recent Observations. Mém. Soc. astron. ital., Vol. 40, No. 2, 1969, pp. 205-209 (1970 2. 51. 287).

43. Cook, A. F. and F. A. Franklin. On the Structure of Saturn's Rings. Astron. J., Vol. 70, No. 2, 1965, pp. 135-136 (1965 12. 51. 486).

44. Cook, A. F. and F. A. Franklin. Particle Sizes in Saturn's Rings. Astron. J., Vol. 71, No. 9, 1966, p. 851 (1967 6. 51. 563).

44a. Danielson, R. E. and M. G. Tomasko. A Two-Layer Model of the Jovian Clouds. J. Atmosph. Sci, Vol. 26, No. 5, Part I, 1969, pp. 889-897 (1970 9. 51. 281).

45. Dauviller, A. The Internal Structure of the Giant Planets. C. r. Acad. sci., Vol. 237, No. 17, 1953, pp. 951-953 (1954 5-3559).

46. Eck, R. V. Predictions of the Compositions of the Atmospheres of the Planets. Proc. 18th Annual Conf. Engng Med. and Biol., Philadelphia, Pa. 1965, Vol. 7, Philadelphia, Pa., 1965, p. 185 (1966 7. 51. 475).

47. Ellis, G. R. A. Cyclotron Radiation from Jupiter. Austral. J. Phys., Vol. 15, No. 3, 1962, pp. 344-353 (1963 7. 51. 326).

48. Ellis, G. R. A. The Radio Emissions from Jupiter and the Density of Jovian Exosphere. Austral. J. Phys., Vol. 16, No. 1, 1963, pp. 74-81 (1964 1. 51. 374).

49. Field, G. B. and J. E. Gaustad. Meteoric Dust Particles and the Anomalous Polarization of Jupiter. Astron. J., Vol. 65, No. 6, 1960, p. 344 (1961 6A 496).

50. Field, G. B. Can the Jupiter Emission be Cyclotron Radiation? Astron. J., Vol. 66, No. 7, 1961, p. 283 (1962 3A 347).

51. Fielder, C. and R. Kurth. On the Mass Distribution in the Interiors of the Jovian Planets. Z. Astrophys., Vol. 44, No. 2, 1958, pp. 106-111 (1958 8-5001).

52. Franklin, F. A. and A. F. Cook. II. Note on the Nature of Saturn's Rings. Astron. J., Vol. 63, No. 9, 1958, pp. 398-400 (1960 9-9092).

53. Greenspan, J. A. and T. Owen. Jupiter's Atmosphere: Its Structure and Composition. Science, Vol. 156, No. 3781, 1967, pp. 1489-1494 (1968 9. 51. 467).

54. Gross, S. H. and S. I. Rasool. The Upper Atmosphere of Jupiter. Icarus, Vol. 3, No. 4, 1964, pp. 311-322 (1965 8. 51. 287).

55. Harrison, H. and R. I. Schoen. Evaporation of Ice in Space: Saturn's Rings. Science, Vol. 157, No. 3793, 1967, pp. 1175-1176 (1968 4. 51. 557).

55a. Henry, R. J. and M.BB. McElroy. The Absorption of Extreme Ultraviolet Solar Radiation by Jupiter's Upper Atmosphere. J. Atmosph. Sci., Vol. 28, No. 5, Part I, 1969, pp. 912-917 (1970 8. 51. 280).

56. Hertz, H. G. A Determination of the Mass of Saturn. Astron. J., Vol. 58, No. 2, 1953, p. 42 (1953 2-848).

57. Herzberg, G. and J. W. Johns. C. The Red Bands of CH_2 and Their Possible /157 Importance in the Spectra of the Major Planets. Mém. Soc. roy. sci. Liège, Vol. 7, No. 1, 1963, pp. 117-124 (1964 1. 51. 496).

58. Hess, S. L. The General Atmospheric Circulation of Jupiter. The Study of Planetary Atmospheres. Final Report, Lowell Obs., 1952, 47-54.

59. Hide, R. Origin of Jupiter's Great Red Spot. Nature (Engl.), Vol. 190, N. 4779, 1961, pp. 895-896 (1962 7A 514).

60. Hide, R. On the Hydrodynamics of Jupiter's Atmosphere. Mem. Soc. roy. sci. Liege, Vol. 7, No. 1, 1963, pp. 481-505 (1964 1. 51. 509)

61. Hide, R. Planetary Magnetic Fields. Planet. and Space Sci., Vol. 14, No. 7, 1966, pp. 579-586 (1966 12. 51. 436).

62. Hide, R. On the Circulation of the Atmospheres of Jupiter and Saturn. Planet and Space Sci., Vol. 14, No. 8, 1966, pp. 669-675 (1967 2. 51. 538).

63. Hide, R. On the Dynamics of Jupiter's Interior and the Origin of His Magnetic Field. Magnetism and Cosmos. Edinburgh - London, Oliver and Boyd, 1967, pp. 378-395 (1967 7. 51. 505).

64. Hide, R. Jupiter's Great Red Spot. Scient. Amer., Vol. 218, No. 2, 19 1968, pp. 75-82 (1968 8. 51. 522).

64a. Hide, R. Dynamics of the Atmospheres of the Major Planets with an Appendix on the Viscous Boundary Layer at the Rigid Bounding Surface of an Electrically-Conducting Rotating Fluid in the Presence of a Magnetic Field. J. Atmosph. Sci., Vol. 26, No. 5, Part I, 1969, pp. 841-853 (1970 9. 51. 275).

65. Hide, R. and A. Ibbetson. An Experimental Study of "Taylor Columns". Icarus, Vol. 5, No. 3, 1966, pp. 279-290 (1967 2. 51. 537).

66. Hide, R. and A. Ibbetson. Taylor Columns. Magnetism and Cosmos. Edinburgh - London, Oliver and Boyd, 1967, pp. 343-347 (1967 12. 51. 254).

66a. Hogan, J. S., S. I. Rasool, and T. Encrenaz. The Thermal Structure of the Jovian Atmosphere. J. Atmosph. Sci., Vol. 26, No. 5, Part I, 1969, pp. 898-905 (1970 9. 51. 282).

67. Huang Su-Shu. The Problem of Nitrogen Peroxide in the Atmospheres of Planets. Publs Astron. Soc. Pacif., Vol. 73, No. 435, 1962, pp. 446-451 (1962 10A 210).

68. Hubbard, W. B. Internal Temperature of Jupiter and Saturn. Astron. J., Vol. 73, No. 5, Part 2, 1968, p. 100.

69. Hugh, K. H. Calculated Physical Properties of Planets in Relation to Composition and Gravitational Layering. J. Geophys. Res., Vol. 72. No. 12, 1967, pp. 3179-3197.

69a. Hunten, D. M. The Upper Atmosphere of Jupiter. J. Atmosph. Sci., Vol. 26, No. 5, Part I, 1969, pp. 826-834 (1970 9. 51. 276).

70. Ibele, W. E. and T. F. Irvine, Jr. Certain Thermodynamic and Transport Properties of the Atmospheres of Venus, Mars and Jupiter. Paper Amer. Soc. Mech. Engrs., N A - 102, 1959, 6 pp. (1960 12-12360).

70a. Ingersoll, A. P. Inertial Taylor Columns and Jupiter's Great Red Spot. J. Atmosph. Sci., Vol. 26, No. 4, 1969, pp. 744-752 (1970 6. 51. 288).

71. Jeffreys, H. On the Internal Constitution of Jupiter and Saturn. Monthly Notices Roy. Astron. Soc., Vol. 84, No. 7, 1924, pp. 534-538.

72. Kaplan, L. D. On the Temperature and Radiative Balance of Jupiter's Atmosphere. Trans. Internat. Astron. Union., XIIB (1964), 1966, p. 215.

73. Klepczynski, W. J. Mass of Jupiter Derived from the Motion of 52 Europa. Astron. J., Vol. 72, No. 7, 1967, p. 808 (1968 3. 51. 505).

73a. Kovalevsky, J. and F. Link. The Temperature of Neptune. C. r. Acad. Sci., Vol. 267, No. 22, 1968, pp. B1241-B1244 (1969 4. 51. 579).

74. Lasker, B. M. Wet Adiabatic Model Atmospheres for Jupiter. Astrophys. J., Vol. 138, No. 3, 1963, pp. 709-719 (1964 7. 51. 221).

74a. Lewis, J. S. Observability of Spectroscopically Active Componnds in the Atmosphere of Jupiter. Icarus, Vol. 10, No. 3, 1969, pp. 393-409 (1970 4. 51. 286). /158

74b. Lewis, J. S. The Coulds of Jupiter and the NH_3 - H_2O and NH_3 - H_2S Systems. Icarus, Vol. 10, No. 3, 1969, pp. 365-378 (1970 5. 51. 284).

75. Link, F. Relationship of the Terrestrial and Jovian Atmospheric Circulation. Icarus, Vol. 6, No. 1, 1967, pp. 129-131 (1968 1. 51. 491).

76. Lippincott, E. R., R. V. Eck, M. O. Dayhoff, and C. Sagan. Thermodynamic Equilibria in Planetary Atmospheres. Astrophys. J., Vol. 147, No. 2, 1967, pp. 753-764 (1967 10. 51. 238).

77. De Marcus, W. C. Model Atmospheres of Hydrogen Planets. Astron. J., Vol. 58, No. 3, 1953, pp. 36-37 (1953 1-290).

78. De Marcus, W. C. Model Hydrogen Atmospheres. Mém. Soc. roy. sci. Liège, Vol. 18, 1957, pp. 182-185.

79. De Marcus, W. C. Planetary Interiors. Handbuch der Physik. Berlin - Göttingen - Heidelberg, Springer - Verlag, Lii, 1959, pp. 419-448.

80. De Marcus, W. C. The Constitution of Jupiter and Saturn. Astron. J., Vol. 63, No. 1, 1958, pp. 2-28 (1959 7-5333).

81. De Marcus, W. C. Models of Jupiter and Saturn. Magnetism and Cosmos. Edinburgh - London, Oliver and Boyd, 1967, pp. 352-364 (1967 11. 51. 473).

82. De Marcus, W. C. and R. T. Reynolds. The Constitution of Uranus and Neptune. Mem. Soc. roy. sci. Liege, Vol..7, No. 1, 1963, pp. 51-64 (1964 7. 51. 233).

83. De Marcus. W. C. and R. Wildt. Jupiter's Great Red Spot. Nature (Engl.), Vol. 209, No. 5018, 1966, p. 62 (1966 6. 51. 544).

83a. McGovern, W. E. Exospheric Temperatures of Jupiter and Saturn. J. Geophys. Res., Vol. 73, No. 19, 1968, pp. 6361-6363 (1969 5. 51, 522).

83b. McNesby, J. R. The Photochemistry of Jupiter above 1000 Å. J. Atmosph. Sci., Vol. 26, No. 3, 1969, pp. 594-599 (1970 2. 51. 280).

84. Melrose, D. B. Rotational Effects on the Distribution of Thermal Plasma in the Magnetosphere of Jupiter. Planet. and Space Sci., Vol. 15, No. 2, 1967, pp. 381-393 (1967 8. 51. 577).

85. Miles, B. and W. H. Ramsey. On the Internal Structures of Jupiter and Saturn. Monthly Notices Roy. Astron. Soc., Vol. 112, No. 2, 1952, pp. 234-243.

86. Milford, S. N. and F. R. Pomill. On the Atmosphere of the Galilean Satellites of Jupiter. Astron. J., Vol. 72, No. 7, 1967, p. 818 (1968 3. 51. 513).

87. Miller, S. L. The Occurrence of Gas Hydrates in the Solar System. Proc. Nat. Acad. Sci. U. S. A., Vol. 47, No. 11, 1961, pp. 1798-1808 (1963 1. 51. 471).

88. Mintz, Y. On the Formation of Disturbances in the Atmosphere of Jupiter in Responce to Changes in the State of the Sun. The Study of Planetary Atmospheres. Final Report, Lowell observ., 1952, pp. 200-207.

89. Mubarak, A. and V. K. Tewary. Internal Structure of Planets. Proc. Nat. Inst. Sci. India, Vol. A28, No. 1, 1962, pp. 191-198 (1963 1. 51. 253).

90. Münch, G. The Thermal Opacity in the Major Planets. Trans. Internat. Astron. Union, XIIB (1964), 1966, p. 214.

91. Nicolet, M. The Effect of Solar Far-Ultraviolet Radiation on the Atmosphere of the Earth and the Other Planets. Mém. Soc. roy. sci. Liège, Vol. 4, 1957, pp. 319-368.

92. O'Handley*, D. A. Determination of the Mass of Jupiter from the Motion of 65 Cybele. Astron, J., Vol. 73, No. 2, Part 2, 1968, p. 29.

---

*Translator's Note: Incorrectly given as O'Hadley in the foreign text.

93. Opik, E. J. Jupiter: Chemical Composition, Structure and Origin of a Giant Planet. Icarus, Vol. 1, No. 3, 1962, pp. 200-257 (1964 3. 51. 475).

94. Opik, E. J. Jupiter: Chemical Composition, Structure,and Origin of a Giant Planet. Mém. Soc. roy. sci, Liège, Vol. 7, No. 1, 1963, pp. 47-50 (1964 1. 51. 508).

95. Opik, E. J. Selective Escape of Gases. Geophys. J. Roy. Astron. Soc., /159
Vol. 7, No. 4, 1963, pp. 490-509 (1964 1. 51. 295).

96. Owen, T. C. and D. O. Staley. A Possible Jovian Analogy to the Terrestrial Equatorial Stratospheric Wind Reversal. J. Atmosph. Sci., Vol. 20, No. 4, 1963, pp. 347-350.

97. Owen, T. and T. E. Walsh. Radiation Balance of Jupiter and Saturn. Nature (Engl.), Vol. 208, No. 5009, 1965, pp. 476-477 (1966 8. 51. 510).

98. Papazian, H. A. The Colors of Jupiter. Publs Astron. Soc. Pacif., Vol. 71, No. 420, 1959, pp. 237-239 (1960 4-3238).

99. Peebles, P. J. E. The Structure and Composition of Jupiter and Saturn. Astrophys. J., Vol. 140, No. 1, 1964, pp. 328-347 (1965 6. 51. 305).

100. Peebles, P. J. E. Are the Interiors of Jupiter and Saturn Hot? Origin and Evolut. Atmosph. and Oceans. New York - London - Sydney, John Wiley and Sons, Inc., 1964, pp. 299-303 (1966 5. 51. 238).

101. Peek, B. M. Jupiter's Great Red Spot. Observatory, Vol. 83, No. 936, 1963, pp. 216-218 (1964 6. 51. 471).

102. Porter, W. S. The Constitution of Uranus and Neptune. Astron. J., Vol. 66, No. 5, 1961, pp. 243-245 (1962 3A 260).

103. Ramsey, W. H. On the Constitution of the Major Planets. Monthly Notices Roy. Astron. Soc., Vol. 111, No. 5, 1951, pp. 427-447.

104. Ramsey, W. H. On the Constitution of Uranus and Neptune. Planet. and Space Sci., Vol. 15, No. 11, 1967, pp. 1609-1623 (1968 5. 51. 252).

105. Rank, D. H., Fink, U., and T. A. Wiggins. Measurements of Spectra of Gases of Planetary Interest. II. H_2, CO_2, NH_3 and CH_4. Astrophys. J., Vol. 143, No. 3, 1966, pp. 980-988 (1966 11. 51. 220).

106. Reese, E. J. A Possible Clue to the Rotation Period of the Solid Nucleus of Jupiter. J. Brit. Astron. Assoc., Vol. 63, No. 6, 1953, pp. 219-221 (1954 2-2292).

107. Reiffel, L. Trapped Radiation Estimates for the Other Planets. Radiation Trapped in Earth's Magnet. Field. Dordrecht - New York, 1966, pp. 256-262 (1967 11. 51. 452).

108. Reynolds, R. T. and A. L. Summers. Models of Uranus and Neptune. J. Geophys. Res., Vol. 70, No. 1, 1965, pp. 199-208 (1965 8. 51. 290).

109. Rice, F. O. Colors on Jupiter. J. Chem. Phys., Vol. 24, No. 6, 1956, p. 1259 (1957 2-1429).

110. Rice, F. O. The Chemistry of Jupiter. Scient. Amer., Vol. 194, No. 6, 1956, pp. 119-128 (1957 - 1430).

111. Rice, F. O. and D. P. Cosgrave. Some Experiments on Rice's Blue Material: Colours on Jupiter. Nature (Engl.), Vol. 188, No. 4755, 1960, p. 1023 (1961 10A 461).

112. Richardson, P. D. and Y. M. Shum. Surface Temperatures of the Galilean Satellites of Jupiter. Nature (Engl.), Vol. 220, No. 5170, 1968, pp. 897-898.

113. Rishbeth, H. The Ionosphere of Jupiter. Austral. J. Phys., Vol. 12, No. 4, 1959, pp. 466-468 (1961 3A 557).

114. Runcorn, S. K. On the Rotation of Jupiter. Magnetism and Cosmos. Edinburgh - London, Oliver and Boyd, 1967, pp. 365-377 (1968 6. 51. 583).

115. Sagan, C. The Production of Organic Molecules in Planetary Atmospheres. Astron. J., Vol. 65, No. 9, 1960, p. 499 (1961 9A 261).

116. Sagan, C. On the Nature of the Jovian Red Spot. Mém. Soc. roy. sci. Liège, Vol. 7, No. 1, 1963, pp. 506-515 (1964 5. 51. 498).

117. Sagan, C. On Radiative Transfer in the Atmosphere of Jupiter. Trans. Internat. Astron. Union, XII B (1964), 1966, p. 215.

118. Sagan, C. E., E. R. Lippincott, M. O. Dayhoff, and R. V. Eck. Organic Molecules and the Coloration of Jupiter. Nature (Engl.), Vol. 213, No. 5073, 1967, pp. 273-274 (1967 10. 51. 493).

119. Sagan, C. and S. L. Miller. Molecular Synthesis in Simulated Reducing Planetary Atmospheres. Astron. J., Vol. 65, No. 9, 1960, p. 499 (1961 9A 260). /160

120. Saslaw, W. C and R. L. Wildey. On the Chemistry of Jupiter's Upper Atmosphere. Icarus, Vol. 7, No. 1, 1967, pp. 85-93 (1968 2. 51. 532).

121. Schoenberg, E. The Dynamics of Jupiter's Atmosphere. Astron. Nachr., Vol. 273, 1943, pp. 113-123.

122. Schoenberg, E. The Equatorial Acceleration on Jupiter. Report of the Mathematics-Natural Sciences Section of the Bayer Academy of Sciences at Munich, 1948 (Munich, 1949), pp. 115-147).

123. Shapiro, R. A quantitative Study of Bright and Dark Sports on Jupiter's Surface. The Study of Planetary Atmospheres. Final Report, Lowell obs., 1952, pp. 97-113.

124. Shimizu, M. The Atomic and Molecular Processes in the Upper Atmosphere of Planets. Rept. Ionosphere and Space Res. Janal, Vol. 20, No. 3, 1966, pp. 271-288 (1967 8. 51. 309).

125. Smoluchowski, R. Internal Structure and Energy Emission of Jupiter. Nature (Engl.), Vol. 215, No. 5102, 1967, pp. 691-695 (1968 7. 51. 504).

126. Sodek, B. A.,and J. C. Redmond. Review of the Possible Existence of a Jovian Biosphere. Bio Science, Vo . 17, No. 2, 1967, pp. 97-99 (1968 3. 51. 510).

127. Squires, P. The Equatorial Clouds of Jupiter. Astrophys. J., Vol. 126, No. 1, 1957, pp. 185-194 (1959 9-7240).

127a. Stone, P. H. An Application of Baroclinic Stability Theory to the Dynamics of the Jovian Atmosphere. J. Atmosph. Sci., Vol. 24, No. 6, 1967, pp. 642-652 (1970 6. 51. 283).

127b. Street, W. B. Phase Equilibria in the Planetary Atmospheres. J. Atmosph. Sci., Vol. 26, No. 5, Part I, 1969, pp. 924-931 (1970 9. 51. 286).

127c. Strobel, D. F. The Photochemistry of Methane in the Jovian Atmosphere. J. Atmosph. Sci., Vol. 26, No. 5, Part I, 1969, pp. 906-911 (1970 8.51. 279).

128. Titman, C. W. Experiments on Taylor Columns over Holes. Magnetism and Cosmos, 1967, pp. 348-351 (1967 12. 51. 255).

129. Trafton, L. M. The Thermal Opacity inthe Major Planets. Astrophys. J., Vol. 140, No. 3, 1964, pp. 1340-1341 (1965 5. 51. 434).

130. Trafton, L. M. The Pressure Induced Monochromatic Translational Absoprtion Coefficients for Homopolar and Nonpolar Gases and Gas Mixtures with Particular Application to H_2. Astrophys. J., Vol. 146, No. 2, 1966, pp. 558-571 (1967 7. 51. 288).

131. Trafton, L. M. Model Atmospheres of the Major Planets. Astrophys. J., Vol. 147, No. 2, 1967, pp. 765-781 (1967 10. 51. 237).

131a. Trafton, L. M. and G. Munch. The Structure of the Atmosphere of the Major Planets. J. Atmosph. Sci., Vol. 26, No. 5, Part I, 1969, pp. 813-825 (1970 9. 51. 273).

132. Urey, H. C. and A. W. Brewer. Fluorescence in Planetary Atmospheres. Proc. Roy. Soc., Vol. A241, No. 1224, 1957, pp. 37-43 (1959 8-6454).

133. Walker, J. C. G and R. Jastrow. The Thermospheres of the Planets. Trans. Amer. Geophys. Union, Vol. 44, No. 1, 1963, p. 85 (1963 12. 51. 464).

134. Warwick, J. W. Theory of Jovian Structure. Proceeding of the Caltech - JPL Lunar and Planetary Conference, 1965, California Institute of Technology, 1966, p. 122.

135. Wildey, R. L. On the Infrared Opacity of Jupiter's Outer Atmosphere. Icarus, Vol. 3, No. 4, 1964, pp. 332-335 (1965 8. 51. 288).

136. Wildey, R. L. On the Interpretation of Thermal Emission Maps of Jupiter. J. Geophys. Res., Vol. 70, No. 15 1965, pp. 3796-3797 (1966 2. 51. 533).

137. Wildt, R. Photochemistry of Planetary Atmospheres. Astrophys. J., Vol. 86, No. 3, 1937, pp. 321-336.

138. Wildt, R. On the Chemical Nature of the Colouration in Jupiter's Cloud Forms. Monthly Notices Roy. Astron. Soc., Vol, 99, No. 8, 1939, pp. 616-623. /161

139. Wildt. R. Planetary Interiors: Introductory Report. Mém. Soc. roy. sci. Liége, Vol. 7, No. 1, 1963, pp. 15-28 (1964 7. 51. 232).

140. Woeller, F. and C. Ponnamperuma. Organic Synthesis in a Simulated Jovian Atmosphere. Icarus, Vol. 10, No. 3, 1969, pp. 386-392 (1970 5. 51. 285).

V. Radioastronomical Investigations

1. Bibinova, V. P., A. D. Kuz'min, A.Ye. Salomonovich, and I. V. Shavlovskiy. Observations of the Radio Emission of Venus and Jupiter at 3.3 cm. Astron. zh., Vol. 39, No. 6, 1962, pp. 1083-1088 (1963 6. 51. 354).

2. Gol'nev, V. Ya., N. M. Lipovka, and Yu. N. Pariyskiy. Observations of Jupiter's Radio Emission at 6.5 cm in Pulkovo. Dokl. AN SSSR, Vol. 157, No. 3, 1964, pp. 554-556 (1964 12. 51. 420).

2a. Yefanov, V. A., A. G. Kislyakov, I. G. Moiseyev, and A. I. Naumov. The Radio Emission of Venus and Jupiter at Wavelengths of 2.25 and 8 mm. Astron. zh., Vol. 46, No. 1, 1969, pp. 147-151 (1969 8. 51. 420).

3. Zheleznyakov, V. V. Radio Emission of the Sun and the Planets. Uspekhi fizicheskikh nauk, Vol. 64, No. 1, 1958, pp. 113-154.

4. Zheleznyakov, V. V. A Thoery of Jupiter's Sporadic Radio Emission. Astron. zh., Vol. 35, No. 2, 1958, pp. 230-240 (1960 5-4143).

5. Zheleznyakov, V. V. Radioizlucheniye Solntsa i planet (Radio Emissions of the Sun and the Planets). Moscow, "Nauka" Press, 1964.

6. Zakharov, A. V., V. D. Krotikov, V. S. Troitskiy, and N. M. Tseytlin. Results of Measurements of the Intensity of the Radio Emission of a Number of Discrete Sources, the Moon, and Jupiter at a Wavelength of 70.16 cm. Izv. vyssh. uchebn. zavedeniy (Proceedings of Higher Educational Institutions). Radiofizika, Vol. 7, No. 3, 1964, pp. 553-555 (1964 12. 51. 360).

7. Kotel'nikov, V. A. L. V. Apraksin, V. M. Dubrovin, M. D. Kislik, B. I. Kuznetsov., G. M. Petrov, O. N. Rzhiga, A. V. Frantsesson, and A. M. Shakhovskiy. Radio Emission of the Planet Jupiter. Dokl. AN SSSR, Vol. 155, No. 5, 1964, pp. 1037-1038 (1964 9. 51. 315).

8. Korol'kov, D. V., Yu. N. Pariyskiy, and G. M. Timofeyeva. Radioastronomical Observations of Jupiter with High Resolving Power. Astron. tsirkulyar, No. 283, 1964, p. 1 (1964 10. 51. 315).

9. Krotikov, V. D., V. S. Troitskiy, and N. M. Tseytlin. Temperature of the Radio Emission of the Moon and Jupiter at 70.16 cm. Astron. zh., Vol. 41, No. 5, 1964, pp. 951-954 (1965 2. 51. 406).

10. Kutuza, B. G., B. Ya. Losovskiy, and A. Ye. Salomonovich. Saturn's Radio Emission at 8 mm. Dokl. AN SSSR, Vol. 161, No. 6, 1965, pp. 1301-1302 (1966 2. 51. 385).

11. Naumov, A. P. and I. P. Khizhnyakov. Jupiter's Thermal Radio Emission. Astron. zh., Vol. 42, No. 3, 1965, pp. 629-638 (1965 2. 51. 345).

12. Pariyskiy, Yu. N. Jupiter's Radiation Belts. Astron. tsirkulyar, No. 285, 1964, pp. 1-2 (1964 10. 51. 316).

13. Rzhiga, O. N. and Z. G. Trunova. Measurement of Jupiter's own Emission in the Decimeter Region. Astron. zh., Vol. 42, No. 1, 1965, pp. 121-123 (1965 7. 51. 355).

14. Slysh, V. I. Measurements of Kilometer Cosmic Radio Radiation in Interplanetary Space. Kosmich. issledovaniya, Vol. 4, No. 6, 1966, pp. 923-931 (1967 4. 62. 207).

15. Alexander, J. K. and R. G. Stone. Low-Level Decameter Emissions from Jupiter. Astron. J., Vol. 69, No. 8, 1964, pp. 529-530 (1965 7. 51. 356).

16. Alexander, J. K. and R. G. Stone. Influence of Satellite Io on the 26.3 Mc/s Emissions from Jupiter. Astrophys. J., Vol. 141, No. 4, 1965, pp. 1587-1588 (1966 3. 51. 424).

16a. Alsop, L. E., J. A. Giordmaine, C. H. Mayer, and C. H. Townes. Observations Using a Maser Radiometer at 3-cm Wave Length. Astron. J., Vol. 63, No. 8, 1958, p. 301 (1960 8. 7741). /162

17. Baart, E. E., C. H. Barrow, and R. T. Lee. Millisecond Radio Pulses from Jupiter. Nature (Engl.), Vol. 211, No. 5051, 1966, pp. 808-810 (1967 4. 51. 382).

18. Baart, E. E., C. H. Barrow, and R. T. Lee. Burst Structure of Jupiter's Decametric Radiation. Astron. J., Vol. 71, No. 6, 1966, pp. 377-378 (1967 3. 51. 419).

19. Barber, D. M. Observations at 610 mgc/sec of the Radiation from Jupiter. Nature (Engl.), Vol. 198, No. 4884, 1963, pp. 947-948 (1964 2. 51. 352).

20. Barber, D. M. The Polarization, Periodicity and Angular Diameter of the Radiation from Jupiter at 610 Mc/s. Monthly Notices Roy. Astron. Soc., Vol. 133, No. 3, 1966, pp. 285-308 (1967 4. 51. 384).

21. Barber, D. M. Synchrotron Radiation from Jupiter at 610 Mc/s. Magnetism and Cosmos. Edinburgh - London, Oliver and Boyd, 1967, pp. 310-317 (1967 11. 51. 345).

22. Barber, D.,and G. L. Moule. Observations at 610 Megacycles/sec of the Radiation from Jupiter. Nature (Engl.), Vol. 198, No. 4884, 1963, pp. 947-948 (1964 2. 51. 352).

23. Barrow, C. H. Magnetic Field of Jupiter. Nature (Engl.), Vol. 188, No. 4754, 1960, pp. 924-925 (1961 9A 467).

24. Barrow, C. H. Recent Radio Observations of Jupiter at Decameter Wavelengths. Astrophys. J., Vol. 135, No. 3, 1962, pp. 847-854 (1963 1. 51. 344).

25. Barrow, C. H. A Brief Survey of the Decametre-Wave Radiation from Jupiter. J. Brit. Astron. Assoc., Vol. 73, No. 1, 1963, pp. 42-48 (1963 9. 51. 324).

26. Barrow, C. H. Polarization observations of Jupiter at Decameter Wavelengths. Mém. Soc. roy. sci. Liége, Vol. 7, No. 1, 1963, p. 563 (1964 2. 51. 357).

27. Barrow, C. H. Polarization of 16 Mc/s Radiation from Jupiter. Nature (Engl.), Vol. 201, No. 4915, 1964, p. 171 (1965 11. 51. 317).

28. Barrow, C. H. Polarization Observations of Jupiter at Decameter Wavelengths. Icarus, Vol. 3, No. 1, 1964, pp. 66-71 (1965 4. 51. 281).

29. Barrow, C. H. and E. E. Baart. B and C "Sources" of Jovian Decametric Radiation. Nature (Engl.), Vol. 213, No. 5072, 1967, pp. 165-166 (1968 4. 51. 416).

30. Barrow, C. H. and T. D. Carr. Eighteen-Megacycle Radiation from Jupiter. J. Brit. Astron. Assoc., Vol. 68, No. 2, 1958, pp. 63-69 (1959 11-8989).

31. Barrow, C. H., E. W. Hyde. An Experiment to Study the Relationship Between Radio Noise from Jupiter and Solar Activity. J. Brit. Astron. Assoc., Vol. 73, No. 8, 1963, pp. 327-328 (1964 7. 51. 312).

32. Barrow, C. H., G. M. Resh, F. W. Hyde, G. M. Greeber, and M. C. Bosch. Spaced-Site Observations of Jupiter in 1963. Nature (Engl.) Vol. 204, No. 4959, 1964, pp. 637-638 (1965 6.51. 397).

33. Barrow, C. H. and J. R. Williams. Possible Continuum Emission from Jupiter at 18 Mc/s. Astron. J., Vol. 72, No. 7, 1967, p. 785 (1968 3. 51. 364).

34. Barrow, C. H. and J. R. Williams. Evidence of Continuum Emission from Jupiter at 18 Mc/s. Nature (Engl.), Vol. 216, No. 5114, 1967, pp. 462-463 (1964 5. 51. 364).

35. Bash, F. N., F. D. Drake, E. Gunderman, and C. E. Heiles. 10 cm Observations of Jupiter, 1961 - 1963. Astrophys, J., Vol. 139, No. 3. 1964, pp. 975-985 (1965 2. 51. 408).

36. Berge, G. L. The Brightness Distribution of Jupiter's 10 and 21 cm Radio Emission. Astron J., Vol. 70, No. 2, 1965, pp. 132-133 (1965 9. 51. 320).

37. Berge, G. L. Circular Polarization of Jupiter's Decimeter Radiation. /163
Astrophys. J., Vol. 142, No. 4, 1965, pp. 1688-1693 (1966 7. 51. 340).

38. Berge, G. L. Interferometry of Jupiter in Decimeter Range. Proceeding of the Caltech - JPL Lunar and Planetary Conference, 1965. California Institute of Technology, 1966, pp. 117-121.

39. Berge, G. L. An Interferometric Study of Jupiter's Decimeter Radio Emission. Astrophys. J., Vol. 146, No. 3, 1966, pp. 767-798 (1967 6. 51. 386).

40. Berge, G. L. Recent Planetary Observations at 3. 12 cm. Publs Astron. Soc. Pacif., Vol. 79, No. 470, 1967, p. 428 (1968 8. 51. 527).

41. Berge, G. L. and D. Morris. Decimeter Measurements Relating to the Possible Displacement of Jupiter's Magnetic Dipole. Astrophys. J., Vol. 140, No. 3, 1964, pp. 1330-1332 (1965 6. 51. 396).

41a. Berge, G. L. and R. B. Read. The Microwave Emission of Saturn. Astrophys. J., Vol. 152, No. 3, Part I, 1968, pp. 755-764 (1969 2. 51. 493).

42. Bigg, E. K. Influence of the Satellite Io on Jupiter's Decametric Emission. Nature (Engl.), Vol. 203, No. 4949, 1964, pp. 1008-1010 (1965 8. 51. 386).

43. Bigg, E. K. Periodicities in Jupiter's Decametric Radiation. Planet. and Space Sci., Vol. 14, No. 8, 1966, pp. 741-758 (1967 4. 51. 387).

44. Boischot, A., M. Ginat, and I. Kazes. Observation of the Planet Jupiter with the Help of the New Radio Telescope at Nancay. C. r. Acad. sci., Vol. 254, No. 14, 1962, pp. 2527-2529 (1963 1. 51. 343).

45. Boischot, A., M. Ginat, and I. Kazes. Observations of the Radiation of the Planets Venus and Jupiter at Wavelengths of 13 cm and 21 cm. Ann. astrophys., Vol. 26, No. 4, 1963, pp. 385-390 (1964 4. 51. 314).

46. Branson, N. J. B. A. High Resolution Radio Observations of the Planet Jupiter. Monthly Notices Roy. Astron. Soc., Vol. 139, No. 2, 1968, pp. 155-162 (1968 11. 51. 472).

47. Briggs, M. H. The Colouring Matter and Radio Emission of Jupiter. Observatory, Vol. 80, No. 917, 1960, pp. 159-161.

48. Brown, G. W., T. D. Carr, and W. F. Block. Long - Baseline Interferometry of S - Bursts from Jupiter. Astrophys. Letters, Vol. 1, No. 3, 1968, pp. 89-94.

49. Brown, G. W., T. D. Carr, and W. F. Block. Long - Baseline Interferometry of Jupiter at 18 Mc/s. Astron. J., Vol. 73, No. 2, Part 2, 1968, p. 6 (1968, 11, 51. 474).

50. Carr, T. D. Guidance of Jupiter's Decameter Radiation by the Planetary Magnetic Field. Trans. Amer. Geophys. Union, Vol. 44, No. 1, 1963, p. 92 (1964 2. 51. 359).

51. Carr, T. C., G. W. Brown, A. G. Smith, C. S. Higgins, H. Bollhagen, J. May, and J. Levy. Spectral Distribution of the Decameter Radiation from Jupiter in 1961. Astrophys. J., Vol. 140, No. 2, 1964, pp. 778-795 (1965 4. 51. 279).

52. Carr, T. D., S. Gulkis, H. Bollhagen, D. J. Kennedy, and A. G. Smith. Circularly Polarized Components of the Decameter Radiation from Jupiter. Astron J., Vol. 70, No. 5, 1965, p. 319 (1965 12. 51. 346).

53. Carr, T. D., S. Gulkis, A. G. Smith, J. May, G. R. Lebo, D. J. Kennedy, and H. Bollhagen. Results of Recent Investigations of Jupiter's Decametric Radiation. J. Res. Nat. Bur. Standards, Vol. D. 69, No. 12, 1965, pp. 1530-1536 (1966 8. 51. 354).

54. Carr, T. D., A. G. Smith, and H. Bollhagen. Evidence for the Solar Corpuscular Origin of the Decameter - Wavelength Radiation from Jupiter. Phys. Rev. Letters, Vol. 5, No. 9, 1960, pp. 418-420 (1961 7A 303).

55. Carr, T. D., A. G. Smith, H. Bollhagen, N. F. Six, and N. E. Chatterton. Recent Decameter Wave - Length Observations of Jupiter, Saturn,and Venus. Astrophys. J., Vol. 134, No. 1, 1961, pp. 105-125 (1962 6A 354).

56. Carr, T. D., A. G. Smith, C. S. Higgins, H. Bollhagen, and J. May. Statistical Spectrum of Jupiter at Decameter Wavelengths. Astrophys. J., Vol. 67, No. 9, 1962, pp. 572-573 (1963 11. 51. 321).

57. Carr, T. D., A. G. Smith, R. J. Leacock, and H. Bollhagen. Polarization of the Radiation from Jupiter at 22.2 Mc/sec. J. Geophys. Res., Voo Vol. 67, No. 9, 1962, pp. 35-48 (1963 6. 51. 358).

58. Carr, T. D., A. G. Smith, R. Pepple, and C. H. Barrow. 18-Megacycle Observations of Jupiter in 1957. Astrophys. J., Vol. 127, No. 2, 1958, pp. 274-283 (1959 9-7132).

59. Chang, D. B. Amplified Whistlers as the Source of Jupiter's Sporadic Decameter Radiation. Astrophys. J., No. 138, No. 4, 1963, pp. 1231-1241 (1964 12. 51. 362).

60. Chang, D. B. and Leverett Davis, Jr. Synchrotron Radiation as the Source of Jupiter's Polarized Decimeter Radiation. Astrophys. J., Vol. 136, No. 2, 1962, pp. 567-581 (1963 9. 51. 321).

61. Chang, D. B. and L. Davis, Jr. Synchrotron Radiation as the Source of the Polarized Decimeter Radiation from Jupiter. Astron. J., Vol. 67, No. 2, 1962, pp. 112-113 (1962 11A 369).

62. Clark, T. A. and J. K. Alexander. Absolute Position of the Jovian Decametric Radio Source. Astron. J., Vol. 72, No. 3, 1967, p. 294.

63. Clark, T. A. and G. A. Dulk. Observation of Jupiter at 8, 9 and 10 Mhz. Astron. J., Vol. 71, No. 3, 1966, p. 158 (1966 11. 51. 333)

64. Conway, R. G., and P. P. Kronberg. A New Determination of the Position of Jupiter's Magnetic Axis. Planet. and Space Sci., Vol. 16, No. 4, 1968, pp. 445-448 (1968 11. 51. 480).

65. Cook, J. J., L. G. Cross, M. E. Bair, and C. B. Arnold. Radio Detection of the Planet Saturn. Nature (Engl.), Vol. 188, No. 4748, 1960, pp. 393-394 (1961 7A 304).

66. Cower, J. F. R. Radiation from Jupiter at 178 Mc/sec. Nature (Engl.), Vol. 199, No. 4900, 1963, p. 1273 (1964 3. 51. 345).

67. Davies, R. D. and D. Williams. Observations of the Continuum Emission from Venus, Mars, Jupiter and Saturn at 21.2-cm Wavelength. Planet. and Space Sci., Vol. 14, No. 1, 1966, pp. 15-32 (1966 7. 51. 337).

68. Davies, R. D and D. Williams. 21.2-cm Observations of the Planets Venus, Mars, Jupiter and Saturn. Magnetism and Cosmos. Edinburgh - London, Oliver and Boyd, 1967, pp. 288-291 (1968 4. 51. 414).

69. Dickel, J. R. Lack of Effect of Io on Jovian 3.75-cm Emission. Nature (Engl.), Vol. 206, No. 4990, 1965, pp. 1241-1242 (1965 12. 51. 348).

70. Dickel, J. R. Observations of Jupiter at a Frequency of 610.5 Mhz. Astron. J., Vol. 71, No. 3, 1966, pp. 519-160 (166 10. 51. 328).

71. Dickel, J. R. Microwave Observations of Jupiter. Magnetism and Cosmos, 1967, pp. 296-309 (1968 4. 51. 417).

72. Dickel, J. R. 6-cm Observations of Jupiter. Astrophys. J., Vol. 148, No. 2, Part I, 1967, p. 535 (1967 11. 51. 343).

73. Douglas, J. N. A Uniform Statistical Analysis of Jovian Decameter Radiation, 1950 - 1960. Astron. J., Vol. 65, No. 9, 1960 pp. 487-488 (1962 7A 360).

74. Douglas, J. N. Time Structure of Jovian Decametric Radiation. Trans. Amer. Geophys. Union, Vol. 44, No. 4, 1963, p. 887.

75. Douglas, J. N. Stability and Change in Rotation Correlation of Jovian Decametric Radiation. Trans. Amer. Geophys. Union, Vol. 44, No. 4, 1963, p. 887 (1964 7. 51. 311).

76. Douglas, J. N. Decametric Radiation from Jupiter. IEEE Trans. Antennas and Propagat., Vol. 12, No. 7, 1964, pp. 839-853 (1965 5. 51. 323).

77. Douglas, J. N. Time Structure of Jupiter's Decametric Emission. Magnetism and Cosmos. Edinburgh - London, Oliver and Boyd, 1967. pp. 337-342 (1967 11. 51. 311).

78. Douglas, J. N. and H. J. Smith. Presence and Correlation of Fine Structure in Jovian Decametric Radiation. Nature (Engl.), Vol. 192, No. 4804, 1961 p. 741 (1962 8A 341).

79. Douglas, J. N. and H. J. Smith. Change in Radiation Period of Jupiter's /165 Decameter Radio Sources. Nature (Engl.), Vol. 199, No. 4898, 1963, pp. 1080-1081 (1964 5. 51. 365).

80. Douglas, J. N. and H. J. Smith. Decametric Radiation from Jupiter. I. Synoptic Observations 1957 - 61. Astron. J., Vol. 68, No. 3, 1963, pp. 163-180 (1964 2. 51. 353).

81. Douglas, J. N. and H. J. Smith. Observations Bearing on the Mechanism of Jovian Decametric Emission. Mém. Soc. roy. sci. Liège., Vol. 7, No. 1., 1963, pp. 551-562 (1964 2. 51. 356).

82. Douglas, J. N and H. J. Smith. Interplanetary Scintillation in Jovian Decametric Radiation. Astrophys. J., Vol. 148, No. 3, Part I, 1967, pp. 885-903 (1968 3. 51. 363).

83. Dowden, R. L. Polarization Measurements of Jupiter Radio Bursts at 10.1 Mc/sec. Austral. J. Phys., Vol. 16, No. 3, 1963, pp. 398-410 (1964 10. 51. 317).

84. Drake, F. D. Microwave Spectrum of Saturn. Nature (Engl.), Vol. 195, No. 4, 1962, pp. 844, 893-894 (1963 6. 51. 359).

85. Drake, F. D. and H. I. Ewen. A Broad-Band Microwave Source Comparison Radiometer for Advanced Research in Radio Astronomy. Proc. Inst. Radio Engrs, Vol. 46, No. 1, 1958, pp. 53-60 (1958 8-5063).

86. Drake, F. D. and C. E. Heiles. Analysis of Planetary Surface Parameters Through Observation of Polarized Thermal Radio Emission. Astron. J., Vol. 69, No. 8, 1964 p. 539 (1965 5. 51. 322).

87. Drake, F. D. and S. Hvatum. Non-Thermal Microwave Radiation from Jupiter. Astron. J., Vol. 64, No. 8, 1959, pp. 329-330 (1960 10. 10141).

88. Duggal, S. P.,aM. A. Pomerantz, and S. E. Forbush. Magnetosphere of Jupiter. Nature (Engl.), Vol. 214, No. 5084, 1967, pp. 155-156 (1967 10. 51. 495).

89. Dulk, G. A. Influence of the Satellite Io on the Decametric Radio Emission from Jupiter. Astron J., Vol. 70, No. 2, 1965, p. 137 (1965 10. 51. 260).

90. Dulk, G. A. Io - Related Radio Emission from Jupiter. Science, Vol. 148, No. 3677, 1965, pp. 1585-1589 (1965 12. 51. 349).

91. Dulk, G. A. The Effect of Io on the Rapid Emission of Jupiter. Proceeding of the Caltech - JPL Lunar and Planetary Conference, 1965. California Institute of Technology, 1966, pp. 134-136.

92. Dulk, G. A. Lack of Effects of Satellites Europa, Ganymede, Callisto and Amalthea on the Decametric Radio Emission of Jupiter. Astrophys. J., Vol. 148, No. 1, Part 1, 1967, pp. 239-248 (1967 11. 51. 341).

93. Dulk, G. A. Apparent Changes in the Rotation Rate of Jupiter. Icarus, Vol. 7, No. 2, 1967, pp. 173-182 (1968 5. 51. 470).

94. Dulk, G. A. and T. A. Clark. Almost-Continuous Radio Emission from Jupiter at 8, 9 and 10 Mhz. Astrophys. J., Vol. 145, No. 3, 1966, pp. 945-948 (1967 4. 51. 383).

95. Dulk, G. A., B. Rayhrer, and R. S. Lawrence. The Size of Jupiter's Decametric Radio Source. Astrophys. J., Vol. 150, No. 2, Part 2, 1967, pp. 117-120 (1968 6. 51. 452).

96. Dulk, G. A. B. Rayhrer, and R. S. Lawrence. Characteristics of Jupiter's Decametric Radio Source Measured with Arc Second Resolution. Astron. J., Vol. 73, No. 2, Part 2, 1968, p. 11 (1968 11. 51. 475).

97. Duncan, R. A. Modulation of Jupiter Decametric Emission by the Satellite Io. Planet. and Space Sci., Vol. 13, No. 10, 1965, pp. 997-1001 (1966 5. 51. 505).

98. Duncan, R. A. Jupiter's Rotation Period. Planet. and Space Sci., Vol. 15, No. 11, 1967, pp. 1687-1694 (1967 7. 51. 517).

99. Ellis, G. R. A. Radiation from Jupiter at 4, 8 Mc/s. Nature (Engl.), Vol. 194, No. 4829, 1962, pp. 667-668 (1963 3. 51. 342).

100. Ellis, G. R. A. Cyclotron Radiation from Jupiter. Austral. J. Phys., Vol. 15, No. 3, 1962, pp. 344-353 (1963 7. 51. 326).

101. Ellis, G. R. A. The Radio Emissions from Jupiter and the Density of Jovian Exosphere. Austral. J. Phys., Vol. 16, No. 1, 1963, pp. 74-81, (1964 1. 51. 374). /166

102. Ellis, G. R. A. and P. M. McCullough. Decametric Radio Emissions of Jupiter. Nature (Engl.), Vol. 198, No. 4877, 1963, p. 275 (1964 3. 51. 351).

103. Ellis, G. R. A. and P. M. McCullough. The Decametric Radio Emission of Jupiter. Augtral. J. Phys., Vol. 16, No. 3, 1963, pp. 380-387 (1964 5. 51. 366).

104. Epstein. E. E. Anomalous Continuum Radiation from Jupiter. Nature (Engl.), Vol. 184, No. 4679, 1959, p. 52 (1960 7-6288).

105. Field, G. B. The Source of Radiation from Jupiter at Decimeter Wavelengths. J. Geophys. Res., Vol. 64, No. 9, 1959, pp. 1169-1177 (1960 7. 6289).

106. Field, G. B. The Source of Radiation from Jupiter at Decimeter Wavelengths. 2. Cyclotron Radiation by Trapped Electrons. J. Geophys. Res., Vol. 65, No. 6, 1960, pp. 1661-1671 (1961 4A 429).

107. Field, G. B. The Source of Radiation from Jupiter at Decimeter Wavelengths. 3. Time Dependence of Cyclotron Radiation. J. Geophys. Res., Vol. 66, No. 5 1961, pp. 1395-1405 (1962 7A 359).

108. Field, G. B. Can the Jupiter Emission be Cyclotron Radiation? Astron. J., Vol. 66, No. 7, 1961, p. 283 (1962 3A 347).

109. Flagg, R. S. and T. D. Carr. Wide Bandwidth Observations of the Decametric Bursts from Jupiter. Astrophys. Letters, Vol. 1, No. 2, 1967, pp. 47-53 (1968 6. 51. 451).

110. Flagg, R. S. and T. D. Carr. Wide Bandwidth Observations of the Decametric Bursts from Jupiter. Astron. J., Vol. 73, No. 2, Part 2, 1968, p. 13 (1968 11. 51. 476).

111. Franklin, K. L. and B. F. Burke. Radio Observations of the Planet Jupiter. J. Geophys. Res. Vol. 63, No. 4, 1958, pp. 807-824 (1959 9-7133).

112. Gary, B. An Investigation of Jupiter's 1400 Mc/sec Radiation. Astron. J., Vol. 68, No. 8, 1963, pp. 568-572 (1964 5. 51. 364).

112a. Gerard E. Observations of Saturn, Uranus and Neptune at 11, 13 cm. Astron. and Astrophys, Vol. 2, No. 2, 1969, pp. 246-248 (1969 12. 51. 431).

113. Giordmaine, J. A., L. E. Alsop, C. H. Townes, and C. H. Mayer. Observations of Jupiter and Mars at 3-cm Wavelength. Astron. J., Vol. 64, No. 8, 1959, pp. 332-333 (1960 10-10142).

114. Goldstein, R. M. Radar Observations of Jupiter. Science, Vol. 144, No. 3620, 1964, pp. 842-843.

115. Gopala, R. Influence of the Satellite Io on Jupiter's Decametric Radio Emission. Proc. Indian Acad. Sci., Vol. A66, No. 2, 1967, pp. 112-119 (1968 6. 51. 453).

116. Gordon, Ma. and J. W. Warwick. High Time-Resolution Studies of Jupiter's Radio Bursts. Astrophys. J. Vol. 148, No. 2, Part 1, 1967, pp. 511-533 (1967 11. 51. 342).

117. Gruber, G. M. Possible Contribution of Jupiter's Magnetospheric Tail to the Radio Emissions of the Planet in the Decametric Region. Nature (Engl.), Vol. 208, No. 5017, 1965, pp. 1271-1273 (1966 7. 51. 338).

118. Gruber, G. M. A Further Analysis of Observations of Jupiter's Decametric Radio Noise for the Apparitions of 1960 - 64. Astrophys. J., Vol. 148, No. 2, Part 1, 1967, pp. 541-546 (1967 11. 51. 344).

119. Gulkis, S. and T. D. Carr. Radio Rotation Period of Jupiter. Science, Vol. 154, No. 3746, 1966, pp. 257-259 (1967 4. 51. 388).

120. Gulkis, S. and T. D. Carr. Asymmetrical Stop Zones in Jupiter's Exosphere. Nature (Engl.), Vol. 210, No. 5041, 1966, pp. 1104-1105 (1967 2. 51. 374).

120a. Gulkis, S. and T. R. McDonough. The Microwave Spectrum of Saturn. Icarus, Vol. 10, No. 3, 1969, pp. 421-427 (1970 5. 51. 293).

121. Haddock, F. T. and J. R. Dickel. The Phase Variation of Venus and /167
the Jovian Polarization Rocking Effect at λ 3.75 cm. Trans. Amer. Geophys. Union, Vol. 44, No. 4, 1963, pp. 886-887 (1964 8. 51. 309).

122. Hardebeck, H. E. Radiometric Observations of Jupiter at 430 Mc/sec. Astrophys. J., Vol. 141, No. 2, 1965, p. 837 (1965 11. 51. 374).

123. Hirshfield, J. L. and G. Bekefi. Decameter Radiation from Jupiter. Nature (Engl.), Vol. 198, No. 4875, 1963, pp. 20-22 (1964 3. 51. 350).

124. Hyde, F. W. Mysterious Radio Emissions from the Planet Jupiter. New Scientist., Vol. 19, No. 354, 1963, pp. 432-435 (1964 5. 51. 367).

125. Hughes, M. P. Planetary Observations at a Wavelength of 6 cm. Planet. and Space Sci., Vol. 14, No. 10, 1966, pp. 1017-1022 (1967 2. 51. 373).

126. Jelley, J. V. Comments on a Recent Theory of the Decametre Radio Storms of Jupiter. Observatory, Vol. 83, No. 933, 1963, pp. 61-63 (1964 2. 51. 361).

127. Kellerman, K. I. The Thermal Radio Emission from Mercury, Venus, Mars, Saturn and Uranus. Icarus, Vol. 5, No. 5, 1966, pp. 478-490 (1967 4. 51. 381).

128. Kellerman, K. I. and I. I. K. Pauliny-Toth. The Detection of the Thermal Radio Emission from Uranus and Neptune at 1. 9 cm. Astron. J., Vol. 71. 6, 1966, p. 390 (1967 3. 51. 421).

129. Kellerman, K. I.,and I. I. K. Pauliny-Toth. Observations of the Radio Emission of Uranus, Neptune and ther Planets at 1. 9 cm. Astron. J., Vol. 145, No. 3, 1966, pp. 954-957 (1967 4. 51. 389).

130. Klein, M. J. and T. V. Seling. Radio Emission from Uranus at 8 Gc/s. Astrophys. J., Vol. 146, No. 2, 1966, pp. 599-602 (1967 5. 51. 339).

131. Komesaroff, M. M. Recent Radio Observations of Jupiter. Proceeding of the Caltech - JPL Lunar and Planetary Conference, 1965. California Institute of Technology, 1966, pp. 107-116.

132. Komesaroff, M. M. and P. M. McCullough. The Radio Rotation Period of Jupiter. Astrophys. Letters, Vol. 1, No. 2, 1967, pp. 39-41 (1968 6. 51. 455).

133. Klaus, J. D. Planetary and Solar Emission at 11 Meters Wavelength. Proc. IRE, Vol. 46, 1958, pp. 266-274.

134. Landovitz, L. and L. Marshall. Stimulated Electron Spinflip Transition as the Source of 18-Megacycle Radiation on Jupiter. Nature (Engl.), Vol. 195, No. 4847, 1962, pp. 1186-1187 (1963 6. 51. 357).

135. Lebo, G. P. Frequency Variation of the Degree of which Jupiter's Satellites Control Jovian Decametric Radio Emission. Astron. J., No. 73, No. 2, Part 2, 1968, p. 23 (1968 11. 51. 477).

136. Lebo, G. P., A. G. Smith, and T. D. Carr. Correlation of the Longitudes of the Galilean Satellites with Jupiter's Decametric Radiation. Astron. J., Vol. 70, No. 5, 1965, p. 325 (1965 12. 51. 350).

137. Lebo, G. P., Carr, T. D., and A. G. Smith. Jupiter's Decametric Emission Correlated with the Longitudes of the First Three Galilean Satellites. Science, Vol. 148, No. 3678, 1965, pp. 1724-1725 (1966 2. 51. 384).

138. Lebo, G. P., T. D. Carr, and A. G. Smith. Satellite Influence of Jovian Decametric Radiation. Trans. Amer. Geophys. Union, Vol. 46, No. 1, 1965, p. 144.

139. Long, R. J. and B. Elsmore. Radio Emission from Jupiter at 408 Mc/s. Observatory, Vol. 80, No. 916, 1960, pp. 112-114 (1961 4A 427).

140. McAdam, W. B. The Extent of the Emission Region on Jupiter at 408 Mc/s. Planet. and Space Sci., Vol. 14, No. 11, 1966, pp. 1041-1046 (1967 4. 51. 386).

141. McClain, E. F. A Test for Non-Thermal Radiation from Jupiter at a Wave Length of 21 cm. Astron J., Vol. 64, No. 8, 1959, pp. 339-340 (1960 11-11275).

142. McClain, E. F., J. H. Nichols, and J. A. Waak. Investigation of Variations in the Decimeter-Wave Emission from Jupiter. Astron. J., Vol. 67, No. 10, 1962, pp. 724-727 (1963 9. 51. 322).

143. McDiarmid, I. B. and J. R. Burrows. Dependence of the Position of the Outer Radiation Zone Intensity Maxima on Electron Energy and Magnetic Activity. Canad J. Phys., Vol. 45, No. 9, 1967, pp. 2873-2878 (1968 4. 62. 252). /168

144. Mariani, F. Results on Magnetic Field Inside and Outside the Magnetosphere. Ann. geophys., Vol. 19, No. 2, 1966, pp. 215-242 (1967 12. 62. 336).

145. Marshall, L. and W. F. Libby. Stimulation of Jupiter's Radio Emission by Io. Nature (Engl.), Vol. 214, No. 5084, 1967, pp. 126-128 (1967 11. 51. 338).

146. Mayer, C. H. General Report on Planetary Radio Astronomy. Mém. Soc. roy. sci. Liège, Vol. 7, No. 1, 1963, pp. 99-111 (1964 3. 51. 342).

147. Mayer, C. H. The Temperature of the Planets. Scient. Amer., Vol. 204. No. 5, 1961, pp. 58-65 (1962 1A 499).

148. Mayer, C. H. Thermal Radio Radiation from the Moon and Planets. IEEE Trans. Milit. Electron., Vol. 8, No. 3-4, 1964, pp. 236-247 (1965 5. 51. 321).

149. Mayer, C. H., T. P. McCullough, and R. M. Sloanaker. Observations of Mars and Jupiter at Wave Length of 3.15 cm. Astrophys. J., Vol. 127, No. 1, 1958, pp. 11-16 (1959 5. 3629).

150. Mlodnosky, R. F., D. L. Carpenter, and R. A. Helliwell. Nonthermal Noise Measurements Near Planets. Mém. Soc. roy. sci. Liège, Vol. 7, No. 1, 1963, pp. 220-223 (1964 2. 51. 362).

151. Miller, A. C. and B. L. Gary. Measurements of the Decimeter Radiation from Jupiter. Astron. J., Vol. 67, No. 10, 1962, pp. 727-731 (1963 9. 51. 323).

152. Miller, A. C. and J. Griffin. 1414 Mc/sec Jupiter Observations. Astron. J., Vol. 71, No. 8, 1966, pp. 744-746 (1967 4. 51. 385).

153. Morris, D. and J. F. Bartlett. Polarisation of the 2840 Mc/s Radiation from Jupiter. Mem. Soc. roy. sci. Liege, Vol. 1, No. 1, 1963, pp. 564-568 (1964 3. 51. 348).

154. Morris, D. and G. L. Gerge. Measurements of the Polarization and Angular Extent of the Decimeter Radiation from Jupiter. Astrophys. J., Vol. 136, No. 1, 1962, pp. 276-282 (1964 3. 51. 347).

154a. Morris, D., J. B. Whiteoak, and F. Tonking. The Linear Polarization of Radiation from Jupiter at 6-cm Wavelength. Austral. J. Phys., Vol. 21, No. 3, 1968, pp. 337-340 (1969 2. 51. 474).

155. Olsson, C. N. and A. G. Smith. Decametric Radio Pulses from Jupiter: Characteristics. Science, Vol. 153, No. 3733, 1966, pp. 289-290 (1967 1. 51. 285).

156. Olsson, C. N.,and A. G. Smith. Delineation of Jovian Decametric Sources by Millisecond Pulses. Nature (Engl.), Vol. 214, No. 5092, 1967, p. 999 (1967 11. 51. 339).

157. Olsson, C. N. and A. G. Smith. Apparent Drift of the Radio Rotational Period of Jupiter. Astron. J., Vol. 73, No. 2, Part 2, 1968, p. 30 (1968 11. 51. 479).

158. Pettengill, G. Planetary Radar Astronomy. Solar Syst. Radio Astron. Athens, Ionosph. Inst. Nat. Observ., 1965, pp. 401-411 (1966 9. 51. 406).

159. Piddington, J. H. and J. F. Drake. Electrodynamic Effects of Jupiter's Satellite Io. Nature (Engl.), Vol. 217, No. 5132, 1968, pp. 935-937 (1968 11. 51. 481).

160. Radhakrishnan, V. and J. A. Roberts. Polarization and Angular Extent of the 960 Mc/s Radiation from Jupiter. Phys. Rev. Letters., Vol. 4, No. 10, 1960, pp. 493-494 (1961 4A 428).

161. Riihimaa, J. J. High-Resolution Spectral Observations of Jupiter's Decametric Radio Emission. Nature (Engl.), Vol. 202, No. 4931, 1964, pp. 476-477 (1964 11. 51. 318).

162. Riihimaa, J. J. Radio Astronomy. High-Resolution Spectra of Decametric Radio Bursts from Jupiter. Nature (Engl.), Vol. 209, No. 5021, 1966, pp. 387-388 (1966 7. 51. 339). /169

163. Riihimaa, J. J. Spectral Types of Decametric Radiation from Jupiter. Nature (Engl.), Vol 212, No. 5068, 1966, pp. 1338-1339 (1967 5. 51. 338).

164. Riihimaa, J. J. High-Resolution Spectral Observations of Decametric Radio Bursts from Jupiter. Suomalais. tiedeakat. toimituks., Vol. AVI, No. 206, 1966, 46 pp. (1967 2. 51. 376).

165. Riihimaa, J. J. Faraday Rotation Effects in Spectral Records of Jupiter's Decametric Radiation. Observatory, Vol. 87, No. 956, 1967, pp. 24-26 (1967 11. 51. 348).

166. Riihimaa, J. J. Structured Events in the Dynamic Spectra of Jupiter's Decametric Radio Emission. Astron. J., Vol. 73, No. 4, 1968, pp. 265-270 (1968 11. 51. 478).

167. Rishbeth, H. The Ionosphere of Jupiter. Austr. J. Phys., Vol. 12, No. 4, 1959, pp. 466-468.

168. Roberts, J. A. Radio Emission from the Planets. Planet. and Space Science, Vol. 11, No. 3, 1963, pp. 221-259.

169. Roberts, J. A. Jupiter, as Observed at Short Radio Wavelengths. J. Res. Nat. Bur Standards, Vol. D69, No. 12, 1965, 1543-1552 (1966 8. 51. 356).

170. Roberts, J. A. and R. D. Ekers. The Position of Jupiter's Van Allen Belt. Icarus, Vol. 5, No. 2, 1966, pp. 149-153 (1966 11. 51. 491).

171. Roberts, J. A. and R. D. Ekers. Observations of the Beaming of Jupiter's Radio Emission at 620 and 2650 Mc/s. Icarus, Vol. 8, No. 1, 1968, pp. 160-165 (1968 11. 51. 473).

172. Roberts, J. A. and M. M. Komesaroff. Evidence for Asymmetry of Jupiter's Van Allen Belt. Nature (Engl.), Vol. 203, No. 4947, 1964, pp. 827-830 (1965 2. 51. 407).

173. Roberts, J. A. and M. M. Komesaroff. Observations of Jupiter's Radio Spectrum and Polarization in the Range from 6 cm to 100 cm. Icarus, Vol. 4, No. 2, 1965, pp. 127-156 (1966 2. 51. 383).

174. Roberts, J. A. and G. J. Stanley. Radio Emission from Jupiter at a Wavelength of 31 cm. Publs. Astron. Soc. Pacif., Vol. 71, No. 423, 1959, p. 485 (1961 3A 405).

175. Roberts, M. S. Correlation of Jupiter Decimeter Radiation with Solar Activity. Astron. J., Vol. 67, No. 5, 1962, p. 280 (1963 8. 51. 309).

176. Roberts, M. S. and G. R. Huguenin. The Radiation Belt of Jupiter. Mém. Soc. roy. sci. Liège, Vol. 7, No. 1, 1963, pp. 569-587 (1964 2. 51. 357).

177. Rose, W. K. Centimeter Radiation from Jupiter and Saturn. Magnetism and and Cosmos, 1967, pp. 292-295 (1968 4. 51. 415).

178. Rose, W. K., J. M. Bologna, and R. M. Sloanaker. Linear Polarization of the 3200 Mc/s Radiation from Saturn. Phys. Rev. Letters, Vol. 10, No. 4, 1963, pp. 123-125 (1963 9. 51. 327).

179. Rose, W. K., J. M. Bologna, and R. M. Sloanaker. Linear Polarization of Jupiter, Saturn and Weak Radio Sources Using a 9.4 cm Maser. Astron. J., Vol. 68, No. 2, 1963, p. 78 (1963 12. 51. 340).

180. Runcorn, S. K. and J. R. Dickel. Jupiter's Magnetism. New scientist, Vol. 26, No. 442, 1965, pp. 354-356 (1965 11. 51. 509).

181. Sastry, C. V. Short Term Correlations of Decameter Radio Emission from Jupiter and Solar Activity. Astron. J., Vol. 71, No. 3, 1966, p. 179 (1966 11. 51. 334).

181a. Senquist, E. R. Circular Polarization of Jupiter at 9.26 cm. Nature, Vol. 224, No. 5223, 1969, pp. 1011-1012 (1970 6. 51. 285).

182. Sherill, W. M. Polarization of Jovian Emission at Decameter Wave Lengths. Nature (Engl.), Vol. 205, No. 4968, 1965, pp. 270-271 (1965 9. 51. 319).

183. Sherill, W. M. Polarization Measurements of the Decameter Emission from Jupiter. Astrophys. J., Vol. 142, No. 3, 1965, pp. 1171-1185 (1966 6. 51. 372). /170

184. Sherill, W. M. and M. P. Castles. Survey of the Polarization of Jovian Radiation at Decameter Wavelengths. Astrophys. J., Vol. 138, No. 2, 1963, pp. 587-598 (1964 11. 51. 319).

185. Six, N. F., J. Frank, A. G. Smith, and T. D. Carr. The Variation in Jovian Decameter Activity with the Elongation of the Planet. Trans. Amer. Geophys. Union, Vol. 44, No. 1, 1963, pp. 91-92 (1964 1. 51. 373).

186. Six, N. F., J. R. Holmes, G. R. Lebo, A. G. Smith, and T. D. Carr. Periodicities in the Jovian Decametric Radio Emission. Astron. J., Vol. 71, No. 6, 1966, p. 398 (1967 3. 51. 420).

187. Slee, O. B. A Search for Radio Emission from Uranus at 11.3 cm. Astrophys. J., Vol. 140, No. 2, 1964, pp. 823-824.

188. Slee, O. B. and H. Gent. Decametric Radio Emission from Jupiter. Nature (Engl.), Vol. 216, No. 5112, 1967, pp. 235-238 (1968 6. 51. 450).

189. Slee, O. B. and C. S. Higgins. Long Baseline Interferometry of Jovian Decametric Radio Bursts. Nature (Engl.), Vol. 197, No. 4869, 1963, pp. 781-783 (1964 3. 51. 349).

190. Slee, O. B., and C. S. Higgins. The apparent sizes of the Jovian Decametric Radio Sources. Austral J. Phys., Vol. 19, No. 2, 1966, pp. 167-180 (1967 2. 51. 375).

191. Sloanaker, R. M. Apparent Temperature of Jupiter at a Wave Length of 10 cm. Astron. J., Vol. 64, No. 8, 1959, p. 346 (1960 11. 11276).

192. Sloanaker, R. M. and J. W. Boland. Observations of Jupiter at a Wave Length of 10 cm. Astrophys. J., Vol. 133, No. 2, 1961, pp. 649-656 (1962 1A 383).

193. Smith, A. G. Radio Spectrum of Jupiter. Science, Vol. 134, No. 3479, 1961, pp. 587-595 (1962 9A 331).

194. Smith, A. G. and T. D. Carr. Radio Frequency Observations of the Planets in 1957 - 1958. Astrophys. J., Vol. 130, No. 2, 1959, pp. 641-647 (1961 3A 404).

195. Smith, A. G. and T. D. Carr. A Comparison of Jupiter's Radio Sources with its Visible Markings. Quart. J. Florida Acad. Sco., Vol. 24, No. 3, 1961, pp. 185-196 (1962 6A 356).

196. Smith, A. G., T. D. Carr, and N. F. Six. Results of Recent Decameter-Wavelength Observations of Jupiter. Mém. Soc. roy. sci. Liège, Vol. 7, No. 1, 1963, pp. 543-550 (1964 2. 51. 355).

197. Smith, A.GG., T. D. Carr, N. F. Six, W. Mock, and H. Bollhagen. Result of Decameter-Wavelength Observations of the 1961 Apparition of Jupiter. Astron. J., Vol. 68, No. 5, 1963, p. 292 (1964 2. 51. 354).

198. Smith, A. G., G. R. Lebo, and T. D. Carr. Morphology of Jupiter's Decametric Radio Sources. Magnetism and Cosmos, 1967, pp. 318-338 (1967 11. 51. 346).

199. Smith, A. G., G. R. Lebo, C. N. Olsson, W. F. Block, N. F. Six, and T. D. Carr. Jovian Rotation Periods and the Origin of the Decametric Burst Structure. Proceeding of the Caltech - JPL Lunar and Planetary Conference, 1965. California Institute of Technology, 1966, pp. 128-133.

200. Smith, A. G., G. R. Lebo, N. F. Six, T. D. Carr, H. Bollhagen, J. May, and J. Levy. Decameter Wavelength Observation of Jupiter. The Apparitions of 1961 and 1962. Astrophys. J., Vol. 141, No. 2, 1965, pp. 457-477 (1965 11. 51. 373).

201. Smith, A. G., N. F. Six., T. D. Carr, and G. W. Brown. Occultation Theory of Jovian Radio Outbursts. Nature (Engl.), Vol. 199, No. 4890, 1963, pp. 267-268 (1964 2. 51. 360).

202 Smith, H. J. Longitude Effects in Jovian Decametric Radio Emmision. Astron. J., Vol. 67, No. 9, 1962, pp. 586-587 (1963, 11. 51. 323).

203. Smith, H. J.,and J. N. Douglas. Observations of Planetary Nonthermal Radiation. Paris Sympos. Radio Astron. (1958). Stanford, Calif., Univ. Press, 1959, pp. 53-55 (1961 2A 368). /171

204. Smith, H. J. and J. N. Douglas. Fine Structure in Jovian Decametric Radio Noise. Astron., J., Vol. 67, No. 2, 1962, p. 120 (1968 1. 51. 346).

205. Smith, H. J., B. M. Lasker, and J. N. Douglas. Fine Structure of Jupiter's 20-Megacycle Noise Storms. Astron. J., Vol. 65, No. 9, 1960, p. 501 (1962 7A 361).

206. Staelin, D. H. and R. W. Neal. Observations of Venus and Jupiter near 1 cm Wavelength. Astron. J., Vol. 71, No. 9, 1966, p. 872 (1967 5. 51. 337).

207. Stone, R. G., J. K. Alexander, and W. C. Erikson. Low-Level Decameter Emissions from Jupiter. Astrophys. J., Vol. 140, No. 1, 1964, pp. 374-377 (1965 3. 51. 294).

208. Straka, R. M., C. L. Bennet, and D. Gaunt. Faraday Rotation Measurements of Decameter Wavelength Radiation from the Planet Jupiter. Electron Density Profiles Ionosphere and Exosphere. Amsterdam, N.-Holland Publs. Co.; New York, John Wiley and Sons, Inc., 1966, pp. 567-574 (1967 6. 51. 387).

209. Strom, S. E. and K. M. Strom. A Possible Mechanism for Jovian Decameter Bursts. Astron, J., Vol. 67, No. 2, 1962, p. 121 (1963 1. 51. 347).

210. Strom, S. E. and K. M. Strom. A Possible Explanation for Jovian Decameter Bursts. Astrophys. J., Vol. 136, No. 1, 1962, pp. 307-310 (1963 2. 51. 382).

211. Thornton, D. D. and W. J. Welch. 8.35 mm Radio Emission from Jupiter. Icarus, Vol. 2, No. 3, 1963, pp. 228-232 (1964 8. 51. 311).

212. Tiainen, P. O. Dependence of Decametric Radio Emission from Jupiter On the Positions of the First Two Galilean Satellites. Nature (Engl.) Vol. 215, No. 5109, 1967, pp. 1467-1468 (1968 3. 51. 508).

213. Tiainen, P. O. Dependence of Jovian Decametric Radio Emission upon the Positions of the First Three Galilean Satellites of the Planet. Suomalais. tiedeakat. toimituks., Vol. AVI, No. 264, 1967, p. 39S (1968 6. 51. 454).

214. Tiuri, M. E. Decametric Radiation from Jupiter and Ionospheric Disturbances Induced by Artificial Satellites. Planet. and Space Sci., Vol. 15, No. 7,, 1967, pp. 1203-1210 (1968 4. 51. 418).

215. Tolbert, C. W. Observed Millimeter Wavelength Brightness Temperatures of Mars, Jupiter and Saturn. Astron. J., Vol. 71, No. 1, 1966, pp. 30-32 (1966 7. 51. 343).

216. Torgersen, H. Bursts and Pulses in the Jupiter Decameter Emission. Astron. J., Vol. 72, No. 7, 1967, pp. 832-833 (1968 3. 51. 365).

217. Warwick, J. W. New Information on Jupiter's Magnetic Field. Trans. Amer. Geophys. Union, Vol. 47, No. 1, 1966, p. 44 (1967 1. 51. 444).

218. Warwick, J. W. Influences of the Satellite Io on Jupiter's Atmosphere. Summary Paper. NCAR Techn. Note, No. 8, 1965, pp. 223-229 (1966 6. 51. 542).

219. Warwick, J. W. Relation of Jupiter's Radio Emission at Long Wavelength to Solar Activity. Science, Vol. 132, No. 3435, 1960, pp. 1250-1251 (1961 8A 382).

220. Warwick, J. W. Theory of Jupiter's Decameter Radio Emission. Ann. N. Y. Acad. Sci., Vol. 95, No. 1, 1961, pp. 39-60 (1962 11A 370).

221. Warwick, J. W. A Comment on Jupiter's Radio Emission at Long Wavelength in Relation to Solar Activity. Arkiv geofys., Vol. 3, No. 5-6, 1962, p. 497 (1963 7. 51. 327).

222. Warwick, J. W. Dynamic Spectra of Jupiter's Decametric Emission. Astrophys. J., Vol. 137, No. 1, 1963 pp. 41-60 (1964 1. 51. 372).

223. Warwick, J. W. The Relation Between Jupiter's Decametric Emission and Radiation Belts. Mem. Soc. roy. sci. Liege, Vol. 7, No. 1, 1963, p. 588 (1964 2. 51. 358).

224. Warwick, J. W. Repeatability of Jupiter's Decametric Radio Emission. Science, Vol. 140, No. 3568, 1963, pp. 814-816 (1964 4. 51. 315).

225. Warwick. J. W. The Position and Sign of Jupiter's Magnetic Moment. Astrophys. J., Vol. 137, No. 4, 1963, pp. 1317-1318 (1964 4. 51. 316).

226. Warwick, J. W. Theory of Jovian Structure. Proceeding of the Caltech - JPL Lunar and Planetary Conference, 1965. California Institute of Technology, 1966, pp. 122-127.

227. Warwick, J. W. and M. A. Gordon. Frequency and Polarization Structure of Jupiter's Decametric Emission on a 10 msec Time Scale. Astron. J., Vol. 70, No. 5, 1965, pp. 332-333 (1965 12. 51. 347).

228. Warwick, J. W. and G. A. Dulk. Faraday Rotation on Decametric Radio Emissions from Jupiter. Science, Vol. 145, No. 3630, 1964, pp. 380-383 (1965 3. 51. 297).

229. Warwick, J. W. and W. T. Kreiss. Observations of Jupiter's Sporadic Radio Emission in the Range 7.6 - 41 mc/s for the Years 1960 - 1963. IGY Solar Activ. Rept Ser., No. 28, 1964, 6 pp (1965 9. 51. 322).

230. Weaver, H. Some Problems of Planetary Radio Astronomy. Solar Syst. Radio Astron. Athens, Ionosph. Inst. Nat. Observ., 1965, pp. 371-399 (1966 9. 51. 375).

231. Welch, W. J., D. D. Thornton, and R. Lohman. Observations of Jupiter, Saturn and Mercury at 1.53 Centimeters. Astrophys. J., Vol. 146, No. 3, 1966, pp. 799-809 (1967 6. 51. 385).

232. Witting, J. Satellite Roles in Radio Emission from Jupiter. Astron. J., Vol. 71. No. 3, 1966, p. 187 (1966 10. 51. 329).

233. Zabriskie, F. R., W. A. Solomon, and J. P. Hagen, Jr. Low-Frequency Observations of Jupiter. Astron J., Vol. 70, No. 2, 1965, p. 151 (1969 9. 51. 321).

234. Zabriskie, F. R., W. A. Solomon, and J. P. Hagen, Jr. Radiation from Jupiter at Long Wave Lengths. Astron. J., Vol. 71, No. 9, 1966, p. 877 (1967 9. 51. 379).

Translated for National Aeronautics and Space Administration under contract No. NASw 2035, by SCITRAN, P. O. Box 5456, Santa Barbara, California, 93108.

NATIONAL AERONAUTICS AND SPACE ADMISTRATION
WASHINGTON, D.C. 20546

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

U.S.MAIL

NASA 451

C27 001 C1 U 30 720609 S00903DS
DEPT OF THE AIR FORCE
AF WEAPONS LAB (AFSC)
TECH LIBRARY/WLOL/
ATTN: E LOU BOWMAN, CHIEF
KIRTLAND AFB NM 87117

POSTMASTER: ... Postal Manual) Do Not Return

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA TECHNOLOGY UTILIZATION PUBLICATIONS

These describe science or technology derived from NASA's activities that may be of particular interest in commercial and other non-aerospace applications. Publications include:

TECH BRIEFS: Single-page descriptions of individual innovations, devices, methods, or concepts.

TECHNOLOGY SURVEYS: Selected surveys of NASA contributions to entire areas of technology.

OTHER TU PUBLICATIONS: These include handbooks, reports, conference proceedings, special studies, and selected bibliographies.

Details on the availability of these publications may be obtained from:

National Aeronautics and
Space Administration
Code KT
Washington, D.C. 20546

Technology Utilization publications are part of NASA's formal series of scientific and technical publications. Others include Technical Reports, Technical Notes, Technical Memorandums, Contractor Reports, Technical Translations, and Special Publications.

Details on their availability may be obtained from:

National Aeronautics and
Space Administration
Code KS
Washington, D.C. 20546

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546